TECHNOLOGY QUARTERLY.

PUBLISHED BY THE STUDENTS OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

VOL. I. SEPTEMBER, 1887. No. 1.

ON THE CONTROL OF RIVERS AND THE PREVENTION OF FLOODS.

BY A. G. ROBBINS, S.B.

THE subject of river hydraulics is naturally divided into two parts. The first looks to the control of water for power, in which the object to be attained is to increase the discharge during periods of drought, and thus increase the permanent available power; or, in other words, to make the flow of the stream as uniform as possible. In the second, the end in view is to confine the river within its banks during the greatest floods, in order that the property and lives of riparian owners may not be in constant danger.

In considering the control of rivers, the interests of the manufacturer will be treated first. If a stream is to furnish a good water-power, it must fall through a considerable space in a short distance. Moreover, the average flow during any year should be large. This last depends upon the amount and distribution of the rainfall, the character of the drainage area, and, to some extent, upon the temperature. As the permanent available power is limited by the minimum flow of the stream, it is essential that the flow should be as nearly uniform as possible.

The natural factors which tend to cause a uniform flow, briefly stated, are as follows:—

A large number of lakes; extensive forests; a deep, porous soil, having an under stratum of impervious material; a large and broad drainage area; a large rainfall during the season when the evaporation is greatest. This last is favorable for a uniform flow, but not for a large average flow for the year. If it is required to make the average flow uniform throughout the year by artificial methods, then the excess of water

which would flow off during the freshets of any year must be stored, and allowed to increase the flow during the drought of that year; and the greater the variation in flow, the larger the storage capacity necessary.

Numerous gaugings on several New England and some other streams render it easy to calculate the amount of artificial storage necessary to make the flow of those rivers uniform. The results derived from these gaugings are given in the following table:—

RIVER.	Drainage area in square miles.	Number of months in which the flow is less than the average.		Amount of storage necessary to render the flow uniform. Given in per cent of yearly flow.		Number of inches on water-shed that flows off in one year.	
		For a dry year.	For a Series of years.	For a dry year.	For a series of years	For a dry year.	For a series of years.
Croton	329	6	6	26.2	22.0	14.72	25.35
Concord	352	8	8	32.9	31.9	13.33	18.62
Merrimack	4,136	8	7	28.9	26.9	21.13	29.85
Connecticut . . .	10,234	8	7	28.4	27.5	19.16	27.75
Schuylkill	1,800	7	–	21.3	—	8.47	—
Passaic Headwaters . .	50 to 100	7	–	39.0	—	13.44	—

This table shows that, generally, from two to three tenths of the entire yearly discharge of a river must be stored to render the flow uniform during that year. Experience shows that in New England, from twelve to fifteen inches of rainfall over the entire drainage area of a stream is about the minimum average flow throughout the year; this quantity is the maximum permanently available with storage. It therefore follows that the storage-reservoirs must be large enough to hold a depth of from three to four and one-half inches of rainfall over the drainage area of the river.

It is doubtless true that on small streams this can often be realized; while on streams of medium and large drainage areas, the reservoirs necessary would be so large as to render their construction impracticable, unless very favorable sites could be found on which to build them. On very large streams it is certainly not practicable, if possible, to render their flow uniform. It is, however, true that very large streams

are seldom available for power; and if they are, the quantity of water flowing is always greater than can be utilized.

How nearly uniform the flow of streams has been made, can be best learned by referring to actual works.

Winnipiseogee River furnishes one of the best examples of what has been done toward rendering the flow of a stream uniform. The storage capacity of Lake Winnipiseogee has been improved, and, with a few small lakes, it forms the storage reservoirs of the Lake Company,—which is composed of the water-power companies at Lowell and Lawrence. A depth of eighteen inches is not controlled by the Lake Company, but is reserved to improve the powers on the Winnipiseogee River. This depth of water furnishes 2,927,000,000 cubic feet. If this quantity of water were allowed to flow off during the three months when the stream was lowest, it would of itself give a flow of seventy-eight hundredths of a cubic foot per second per square mile of drainage area, which is more than twice as great as the average flow during the lowest season in the case of most of the rivers of a similar size in New England.

Assuming twelve inches of rainfall to flow off in one year, it would require a flow of but one-tenth of a cubic foot per second per square mile as the average flow during the lowest season, to be supplied by the river, to make it the maximum available for power during the three months of lowest water. The flow of the river is probably not less than four tenths of a cubic foot per second per square mile during this time.

In addition, all of the water drawn from the reservoirs of the Lake Company passes through the Winnipiseogee on its way to Lowell and Lawrence. This water would be drawn when the Merrimack is low, and its tributaries would naturally be low at the same time; so that the benefits derived from the water controlled by the powers on the Winnipiseogee would be greatly increased by the water controlled by the Lake Company, and, without doubt, render available the maximum with storage.

The Pachaug, a small stream of Southeastern Connecticut, has been so improved by reservoirs, that the Ashland Cotton Mills, which formerly could run seventy looms only a part of the year because of low water, have increased the number to five hundred looms; and even with this increase the mills have not been obliged to shut down because of low water but once for twenty years.

This increase of over seven hundred per cent was caused by constructing an artificial reservoir, flooding an area of nine hundred acres,

and holding 274,000,000 cubic feet of water; a quantity sufficient to give to the river a flow of fifty-nine hundredths of a cubic foot per second per square mile, and thus, without aid from the river, giving for one fourth of the year a power equal to sixty-seven per cent of the maximum available.

By building dams across the outlets of several large lakes and ponds in its basin, the reservoir capacity on the Salmon Falls River has been increased to at least 1,652,000,000 cubic feet; a quantity of water sufficient to give a flow of sixty-four hundredths of a cubic foot per second per square mile, and to assure from eighty to ninety per cent of the maximum available power during the three driest months of the driest years.

Reservoirs on the Woonasquatucket River are large enough to hold 241,600,000 cubic feet of water, which is enough to give for three months a flow of forty-three hundredths of a cubic foot per second for each square mile that the river drains; a quantity which has proved to be enough to run the mills below for an equal length of time. Although this river is not nearly as well reservoired as the Winnipiseogee or the Pachaug, still its reservoirs furnish twenty-five per cent of the utilized power of the stream.

These examples show that it is not only possible, but practicable, to utilize from twelve to fifteen inches of rainfall over the drainage area of some small New England streams. This part of the country is, however, favored by natural causes: the rainfall is more nearly constant than in other parts of the country, and the topography is such that sites can be found where reservoirs of large capacity may be built without flooding too extensive territory. Nearly all of the reservoirs on the streams mentioned were made by raising the level of lakes or ponds in the hilly districts, a considerable increase in depth being obtained without a large increase in area.

Examples of storage on large rivers are not wanting. The Merrimack and the Androscoggin are two rivers upon which works of improvement in the storage capacity have been most extensive.

The area of the lakes and ponds situated within the basin of the Androscoggin is more than two hundred square miles, or one square mile to each seventeen of the basin. Across the outlets of four of the largest of these lakes dams have been built, which create a reservoir capacity of fully 16,000,000,000 cubic feet; a quantity of water sufficient to fill a reservoir one hundred and eight feet deep, and having an area of five square miles. The estimated minimum flow of the river for three months is forty-four hundredths of a cubic foot per second per square mile.

These reservoirs would add to this fifty-six hundredths of a cubic foot per second per square mile, and thus increase the minimum low-season flow to one cubic foot per second per square mile; a quantity sufficient to render available a rainfall of four and one-half inches during three months, — which is about all that can safely be assumed to flow off during that time.

The storage reservoirs on the Merrimack, which are controlled by the Lake Company, have an area of about one hundred square miles, and an estimated capacity of 7,000,000,000 cubic feet. During five years previous to 1878 water was drawn from these reservoirs, on order from the company, an average of forty-five days in each year, and to the amount of about one fourth of the total capacity.

The following table gives the capacity of the reservoirs on some New England streams, and the influence they have on the flow of those streams:—

STREAM.	Drainage area in square miles.	Capacity of Reservoir, Cubic feet.	Estimated average flow for the three driest months c. f. p. s.* per square mile.	Flow which reservoir could furnish for three months c. f. p. s.* per square mile.	Percentage of increase to flow reservoir could furnish during the three driest months.	Capacity of reservoir in inches on watershed.
Winnipiseogee,	480	2,927,000,000	0.40	0.78	195.0	2.64
Salmon Falls,	334	1,652,000,000	.35	.64	182.8	2.13
Pachaug,	60	274,000,000	.20	.58	295.0	1.97
Androscoggin, at Lewiston,	3,698	16,000,000,000	.40	.56	140.0	1.86
Kennebec,	6,400	25,000,000,000	.41	.51	124.4	1.74
Woonasquatucket,	72	241,600,000	.25	.43	172.0	1.47
Merrimack, at Lawrence,	4,599	7,000,000,000	.39	.20	51.3	0.65
Pawtuxet, S. Br.,	229	28,816,000	.32	.16	50.0	.54
Quinebaug,	725	535,788,000	.22	.10	45.5	.44
Blackstone,	458	154,000,000	.30	.04	1.30	.15

* c. f. p. s.,= cubic feet per second.

The water in the reservoirs would add to the flow of the river two tenths of a cubic foot per second per square mile for three months of the year. The reason that more water was not drawn from the res-

ervoirs on order is probably due to two causes: first, because 2,927,000,000 cubic feet of the water in Lake Winnipiseogee are not controlled by the Lake Company, but are used on the Winnipiseogee River, and would increase the flow of the Merrimack twenty per cent during three months of drought; second, because there was no year of unusual drought during the five years mentioned.

In treating the second part of our subject there are two important interests to be considered, — those of navigators, and those of the land-owners on the borders of the streams to be controlled; and it often happens that improvements which would most benefit one will cause injury to the other. Thus, if the level of the water in a low season is kept up to the minimum required by navigation, whether by means of locks or by narrowing the channel, the tendency to overflow the banks in times of freshets will often be much increased. This tendency may be obviated in a number of ways; principal among these are oblique weirs and movable dams.

An English engineer, in speaking of a river in England, has thus defined the problem: "It was required to be improved so as to retain the waters that the minimum depths in times of drought should be sufficient for the traffic, and yet that the passage of the flood-waters should be so unimpeded that they should pass off without flooding the surrounding country." To do this a weir was constructed diagonally across the bed of the stream, and of such a length, that the area of water-section along the weir, when the water was at the flood limit, was at least equal to the cross-section of the stream above the weir at the same time. By this method the weir had little or no effect in raising the high-water level. This requires the length of the weir to be about three times the width of the stream.

Similar methods have been successfully used on the Severn and Shannon Rivers, the only inconvenience being the locks required to pass the weirs.

In France many improvements have been made on this method by building movable weirs, which can be lowered to the bed of the stream in high water, and then offer no resistance to its flow. During low water they can be quickly and easily raised, and thus dam the water back, and raise it to a navigable depth. Weirs of similar construction are also used on the Ohio and some of its tributaries in this country.

Rivers flowing through large swamps are frequently not confined to one channel, but traverse the swamp through numerous passages, the depths of which are ever changing and never certain. Works in a locality like this consist in confining the stream to one channel, which may

be one of the natural water-ways or an artificial canal. To do this the lateral channels must be closed, either by dams or weirs, or by some method of checking the flow of water through them, and the river thus caused to deposit its silt and perform the work of closing. Bundles of fascines have been used successfully to accomplish this result. Recent works on the Mississippi and Missouri Rivers prove that wire netting may be used to check the velocity of the water, and bring about a silting-up of the river-bed.

The methods of control which have for their primary objects the prevention of floods and the reclamation of land, will be considered in the following order: —

Building of artificial reservoirs.
Construction of levees.
Excavation of cut-offs.
Deviation of tributaries.
Excavation of artificial outlets.

Reservoirs: — The control of rivers by reservoirs has long been advocated by engineers. This plan has the advantage of being favorable to land and navigation interests, and in theory is admirable. European engineers were the first to adopt it, and works which were constructed upon the Loire early in the eighteenth century proved to be serviceable in reducing its floods. At Turens a dam was built which prevents the inundation of St. Etienne, and it also forms the reservoir that supplies the town with water.

It is probably practicable to construct reservoirs in the upper, or torrential parts of rivers, that would be of great service in mitigating floods in those parts; while these same reservoirs could become the source of water supply for cities and towns, and also be of some aid in the improvement of navigation below.

In 1842, M. Valleé, a French engineer, proposed to improve the navition of the Rhone, and reduce the height of its flood several feet by holding back the flood-waters in Lake Geneva. The causes which prevented the carrying out of this project were political, it being considered as otherwise feasible by the most prominent hydraulic engineers of that time.

M. Lombardini, in speaking of improvements on the River Po, considered that the lakes on its tributaries were of great importance in reducing the heights of floods. He believed that the flood-waters of the great tributaries were reduced from one half to one third by these lakes, and, according to his suggestions, works of improvement have been constructed at the outlets of some of them.

A system of reservoirs is now being built at the headwaters of the Mississippi, by which it is proposed to improve the navigation of some of its tributaries below the dams, and also, to some extent, that of the Mississippi itself. As far as completed the work has proved beneficial, having shown that at least one fifth of the rainfall is available for storage; an amount capable of materially improving the navigation below during low water. The three reservoirs completed previous to the year 1886 have a capacity of 71,965,000,000 cubic feet, which is sufficient to give to the Mississippi at St. Paul a flow of about nine thousand cubic feet per second for ninety days.

As these reservoirs will not always be full when the Mississippi is lowest, a flow of about six thousand cubic feet per second for ninety days is all that can be assured. At the lowest stage of the Mississippi at St. Paul, the quantity passing is, according to gauging, five thousand eight hundred cubic feet per second; the increased discharge, due to the reservoirs, will therefore be more than one hundred per cent. It is expected that these reservoirs will have some influence in reducing the local floods, but that they will be of practical utility in preventing extensive floods is not considered to be admissible by the engineers constructing them. On some of the western branches of the Mississippi, the surplus water of the flood season might be held back in reservoirs, and used for irrigation,—a subject that has lately assumed importance in some of the Western States.

Prominent among the many examples of irrigation works of India, where they have been quite fully developed, is one on the Mutha River. A dam built across this river holds back the flood-waters to the extent of 5,266,000,000 cubic feet, and thus forms a reservoir which furnishes the water supply of the city of Poona, and irrigates ninety-eight thousand acres of land. Provision is also made to utilize the power made available by the large fall.

For protection against floods, the method of reservoirs is applicable only to streams of a peculiar character. If a stream is navigable, the interests of shippers would oppose the building of dams across the stream in its navigable parts. Moreover, dams could not be built on streams flowing through a plain, because the damage to the land flooded above would offset the benefit to the land protected below.

For the protection of the Mississippi River, dams could not be built across any of the large tributaries except at their headwaters, because the commercial interests depending upon the free navigation of these streams are too valuable to be thus obstructed. Reservoirs built at the headwaters in the mountains will hold back the water of the floods

above the reservoirs only, but it is true that the rainfall in the mountain districts drained by the Mississippi is much less than the rainfall of the plains below. Add to this the fact that the area of the plains is fully four times that of the mountain districts, and it is difficult to believe that reservoirs on the headwaters of the tributaries of the Mississippi can greatly reduce the floods in the delta,—much less control them. As has been stated, reservoirs that hold back the surplus waters of the upper tributaries, doubtless do improve the navigation for a considerable distance below them; but this water, slowly collecting for three or four months, is not the water that causes the disastrous floods. These are caused by the sudden melting of snow and by heavy storms, by which in a few days vast quantities of water are precipitated. A single storm might sweep through the Mississippi valley, outside the limits of reservoirs in the mountains, and cause floods that would inundate hundreds of square miles of territory, were that territory not protected by other methods than that of reservoirs, which in this case would cease to be a protection.

It has been said that artificial reservoirs would take the place of swamps, which were formerly flooded, and served to hold back the flood-waters and prevent inundations. In the case of small streams flowing through extensive swamps this is true, but observations and measurements on the Mississippi show that swamps do not reduce the height of floods on that river. Before the construction of levees its flood-waters were discharged over the west bank of the river above Memphis, through St. Francis Swamp, to he turned back into the river by the high land at Helena. The water then overflowed the east bank until the bluffs at Vicksburg deflected them again to the west, across the river into the Atchafalaya River, and thence to the Gulf of Mexico. Before any of the great floods reach their highest limit, these swamps discharge as much water into the river at their lower limits as they receive in the portions above. These observations are the foundation of the following conclusions of Humphreys and Abbot: swamps do not reduce the height of floods above or below, but they do retard the rise and fall of the river below, and increase the duration of floods; and they also reduce the height of floods along their borders. These conclusions can be substantiated in another way.

Careful comparison of the height of floods at New Orleans in 1717, before any land was reclaimed, with those a hundred and fifty years later, show that this height has not increased; a fact that would seem to substantiate the result given above.

Levees.— The method of protecting land against overflow by embank-

ments, which increase the height of the natural banks, has been, and now is, the one generally adopted. In every country through which flow rivers liable to produce floods, the system of levees has constituted the principal, and often the only method of relief. This system as applied to the rivers of Italy, has furnished a subject for discussion by engineers of various countries, and is the system usually cited to show the evils produced by levees.

The principal argument against levees is, that as they confine the river to its proper channel, the silt, which formerly was scattered over the entire flooded area, is deposited in the channel, and thus raises the river-bed. This, of course, raises the flood-level, and necessitates the building of higher levees; so that it would seem that levees increase the evil they were designed to prevent. On the other hand, it is claimed that the increase in velocity acquired in confining the river to one channel, will be sufficient to prevent the deposition of silt.

It has been claimed that the bed of the River Po has been raised many feet by the silt deposited in its bed, and which would have been deposited on the fields beyond the banks, but for the levees constructed to restrain the floods. This has subsequently been disproved by levellings of M. Lombardini, which show that the bed had not been raised appreciably during the previous three hundred years.

Works in Japan, however, show that levees, in some cases, may be the means of causing the river-beds to silt up, which would elevate the flood limit, and thus necessitate higher levees. There are instances where the level of the river is forty feet above the level of the plain through which it originally flowed. In building railroads, it has been found more economical to tunnel under some of these rivers, than to build over them. This peculiarity, so noticeable in the rivers of Japan, and not in other countries, is due to the sudden discharge of the flood-waters down the steep and barren slopes of the mountains to the plains below. The absence of forests and the proximity of the plains to the mountains, are favorable for the erosion of material and its subsequent deposit in the river-bed. In general, the construction of levees on European and American rivers has not caused an appreciable elevation of the river-bed.

Confining a river to its channel often proves a hindrance to navigation, by tending for a time to increase the irregularities of the bed of the stream, as may be shown by measurements on the Mississippi at Plumb Point, and at Columbus, Kentucky. These measurements are given in the following table, taken from the Journal of the American Association for the Advancement of Science:—

		Wide section.	Narrow section.
Surface width in feet	High water.	8,840	1,680
	Low water.	7,330	1,375
Mean depth in feet	High water.	23.9	60.7
	Low water.	6.0	23.9
Area of section in square feet . . .	High water.	260,000	94,500
	Low water.	30,220	68,500
Mean velocity, feet per second . . .	High water.	3.67	10.10
	Low water.	2.65	1.15
Fall in feet per mile	High water.	0.26	1.75
	Low water.	1.15	0.07

This table shows, that during low water the area of the wide section is less than that of the narrow section, and that during high water the reverse is true,—a phenomenon due to the levees built along the river-bank. As the velocity must be greater through the section of less area, the relative velocity through the cross-sections will be reversed as the river passes from low to high water, as the table shows.

As the power of a river to erode and transport material depends upon its velocity, the effect will be to fill up during floods, in the same place that it scours during low water. In other words, levees make the bars higher and the pools deeper in high water; a fact which tends to show that the flood-waters build up obstructions to their own discharge. If floods were frequent, these bars would probably not be removed between successive floods, so that they would soon become serious obstacles to navigation.

The same conclusion is reached by studying some measurements made at Columbus, Kentucky. During the floods of 1858, within a period of six months there were four times when the discharge exceeded

1,100,000 cubic feet per second. From the first to the last the height of water necessary to cause this discharge regularly increased; the first, for a rising river, being twenty-nine and one-half feet, and the last, thirty-five feet. For a falling river, the first was thirty-one and six-tenths feet, and the last, thirty-six and nine-tenths feet.

For a given height of water, the discharge of a rising river should certainly be the same, provided these heights occur at short intervals of time; and the same discharge of a falling river should show a constant height of gauge, although higher than that for a rising river, because the slope, and therefore the velocity, is less. In view of this, it is probable that the reason the river discharged as much water before the floods, when the gauge was twenty-nine and one-half feet, as it did after the floods, when the gauge was thirty-five feet, is that the bars at Columbus were raised enough during the floods to elevate the high-water mark five and one-half feet higher than it otherwise would have been.

These facts go to disprove one advantage often claimed for levees, — that as they confine all the water in the channel, the velocity must be increased, and with it the scour, which would deepen the channel and thus lower the high-water mark; a result which would undoubtedly be realized were the channel straight and uniform, or if the amount of water flowing were constant. These last are two factors which must be considered, or the conclusions derived will be erroneous, because levees do not straighten the river, but follow the natural banks.

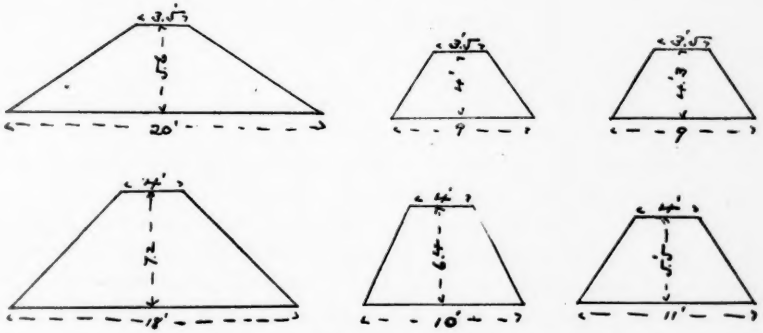
If levees are to be built to confine the flood-waters, the questions arise, where, and how high, and of what cross-section, ought they to be made? As regards position, it is undoubtedly advantageous to place them as near the banks as possible, excepting in places where there is danger of caving banks, because the banks are generally higher than the land back of them, and because the land near the river is the most valuable. In height and cross-section the levees of the Mississippi have been sadly deficient, to which cause many of the disastrous effects of floods may be traced.

Such measurements as those made at Plumb Point and at Columbus furnish an easy, and, within the limits to which it would be necessary to apply it, an accurate method of getting the necessary height of levees sufficient to withstand the force of the greatest floods.

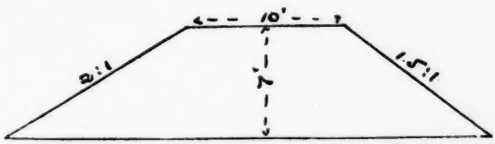
These measurements give the quantity of water flowing, and the corresponding height from low water to ordinary high water forty or fifty feet above. Other measurements have been made by which the total discharge of the river during the greatest floods is determined. If now the quantities discharged from low to high water are plotted on a hori-

zontal line, and the corresponding height of gauge on vertical lines drawn through these points, a curve would be located, from which the height of gauge corresponding to any discharge could be read. If levees are constructed along the banks so that when the river rises above its natural banks the conditions will be similar to those that existed before the ordinary high-water level was exceeded, because the river is still confined to one channel; and the error will not be excessive if the curve which has been located, be extended until it intersects a vertical drawn through the point which gives the maximum discharge of the river during the greatest floods; this last vertical will give the height of levees necessary to confine that flood at that place. By taking measurements at several places along the course of a river, these heights could be determined often enough to fix the height of levees necessary for any place on the stream.

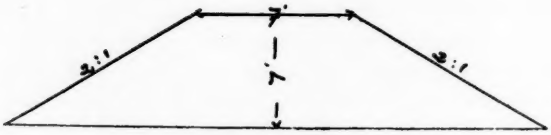
After getting the heights of levees, the necessary cross-section would be fixed by the cross-sections of embankments, holding the same head of water, and which experience has proved to be safe. That the earlier levees built on the Mississippi did not contain a sufficient quantity of material, may be seen by a comparison of the cross-sections of the following embankments:—



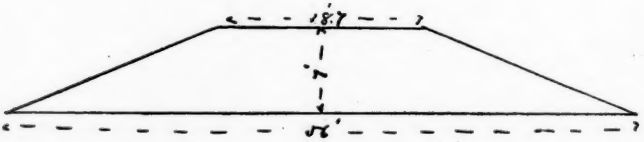
CROSS SECTION OF SOME MISSISSIPPI LEVEES, BUILT BEFORE 1851.



CROSS SECTION OF A DIKE ON THE RHINE.



CROSS SECTION OF A DIKE ON THE PO.



CROSS SECTION OF A LEVEE AS REQUIRED BY THE LAWS OF LOUISIANA.

Cut-offs.— It has been proposed as a means of preventing overflow, that the bends of rivers be cut off, and a new and straight channel formed, through which the water would discharge itself in a shorter time than before. To make this method most effective, the straightening should begin at the mouth of the river, and be continued up stream to the localities it is desired to protect. On some streams where the bends are not numerous, this method might afford an easy and secure means of preventing floods, because the slope would be increased, and with it the velocity; and if the cross-section is not reduced, the discharge being the same, the flood-height would be lowered.

To protect large territories on large and winding streams by cut-offs extending from the mouth upward, could not be economically done; so that in such cases it is important to learn what would be the effect upon the country above and below to make cut-offs somewhere along the course of a river away from the mouth.

If the velocity were increased, because of the increased slope through the cut-off, then it might at first seem as if the water would be poured more rapidly into the river below, and cause it to rise; but if the river did rise, then the slope and cross-section would be increased, which ought to increase the discharge, unless some new factors have been introduced, while in fact the discharge must remain constant.

The real effect of cut-offs can be learned from actual examples on the Mississippi and other rivers. M. Lombardini states, that in the fourteenth century the Po was straightened from Albera to Monticelli, the bends being still visible, while above and below the channel is serpentine. At the head of these cut-offs the levees are only a few feet high, and at the lower end the height is considerably increased; which tends to show that the effect of the cut-offs was to raise the flood-level below.

M. Chattamo says that the effect of a cut-off on the Adige, made in 1854, has been to depress the surface of the river above during the floods since then, and to elevate the surface below,— this elevation being equal to about one half of the depression.

Measurements by Humphreys and Abbot on the Mississippi, show that the effect of the Red River and Raccourci cut-offs on the floods of 1851, was to lower the water from four to four and one-half feet above the cut-off, and to raise the level below about two feet. The American Bend cut-off was made in 1858, and had a similar effect upon the flood levels above and below, during the floods of that year.

If cut-offs do raise the level of the water below, as these measurements show, how can the increased slope and cross-section thus produced be reconciled to the fact that the discharge is the same? It is true that were the river not leveed the discharge through the channel would be increased, because the water that formerly overflowed the banks would now follow the channel; but these measurements were made upon rivers provided with a system of levees, and at a time when the water would not have left the channel had the cut-off not been made. The most probable explanation is that given by Humphreys and Abbot, and which is confirmed by their gaugings and soundings. In a winding river, it is well known that the water is deepest and the velocity greatest near the concave bank. If the bend is cut off, then the greatest velocity will no longer be next the former concave bank, where the river is still deepest, but nearer the center of the stream: the resistance is, therefore, greater, and the slope and cross-section must be increased to discharge the same amount of water.

As far as a single set of measurements can, these show that the character of the river-bed is an important factor to be considered before a cut-off is made. If the river-bed is hard and unyielding material, the power of the water tending to adapt the cross-section to the new velocities will suffice to excavate the bed only after a long time. If, however, the river flows over a bed of its own deposit, the slope of the cross-section will very soon become adapted to the new currents, so that the effect of the cut-off would be beneficial to the country above and not cause trouble below.

Deviation of Tributaries. — This method of controlling rivers is applicable only in rare instances, when the topography of the country is of such a character as to admit of its being done economically. Tributaries that join the main stream far from the sea, cannot be deviated except at great expense; and when a tributary is separated from the main river, the relief from floods is not general. For example: if the

Red River should be made to discharge into the Gulf of Mexico through the Atchafalaya instead of through the Mississippi, the valley below the mouth of the Red River would be relieved from floods caused by that river; but the country above for many hundred miles would not be protected from floods caused by other tributaries above, and which could not be deviated economically.

This plan is only valuable as a supplement to works of a different and a more general character.

Artificial Outlets. — This method, like that of deviating tributaries, cannot be economically adopted unless the natural conditions are favorable. If the outlets are constructed to carry water at all times, then the old channel of the river would be in danger of filling, because the quantity of water would be less and the velocity smaller; a fact which would condemn such outlets on all navigable rivers, unless the outlet itself were made navigable, as has been done on the River Rhone.

When outlets are constructed to carry flood-waters only, they become similar to waste-weirs, and it is necessary to learn whether the water is so charged with silt that a diminution of velocity would cause a deposit. If the water were so charged the effect would be the same as in the first case; but if not, the outlet might be used as an aid to other methods of control.

Measurements show that crevasses made in the levees of the Mississippi cause a deposit below them. As crevasses are simply outlets made by the water instead of by artificial methods, it goes to show that they would not be applicable to that river. In general, it may be said that artificial outlets should be made only in special instances, and after a careful study of the effects likely to be produced.

Mass. Inst. Technology, April, 1887.

METHOD FOR CALIBRATION OF A THERMOMETER AT MANY POINTS.

BY S. W. HOLMAN, S.B.

IN the preparation of thermometers for exact work, it is often important to obtain the calibration corrections; *i. e.*, the corrections for irregularity of the bore of the capillary, for points not far apart on the tube. Most methods which have been given* are applicable only for obtaining corrections at considerable intervals, such, for instance, as

*See Rep. of Brit. Assoc. Adv. Sci. for 1882, p. 145, for review of various methods.

would correspond to three or more centimeters of the capillary. If applied to obtain corrections for shorter intervals, either the accumulated errors enter so largely as to make the result unsatisfactory, or the labor of computation (as in Bessel's method) becomes unduly great. The method to be here described has been devised in the attempt to reach a process by which the accumulation of errors might not seriously affect the result, and yet the labor of observation and computation might not be excessive. While the highest accuracy cannot be claimed for the method, yet it certainly does give satisfactory results with much less labor in observation and computation, than an equally short interval calibration by any other method with which I am acquainted.

The separation of the necessary threads of mercury can be made by sharp but not heavy blows upon the top of the thermometer tube, and by manipulation of the air-bubbles formed by inverting the thermometer and tapping it upon its top. Care and some expertness are essential. Eye-estimation to tenths of a division are supposed in the following description, and if more accurate methods of reading are adopted, the number of settings may be reduced. The use of a small tube, without magnifier, perpendicular to the thermometer is needed, to reduce parallax error.

Suppose the calibration correction desired for every r divisions of the tube. Making r as small as desired will not complicate the work, but will simply increase the labor somewhat less than in inverse proportion to r. Let L, expressed in units of the scale, be the total length to be calibrated.

A summary of the method is as follows: Separate a thread of mercury of length about $\frac{1}{6}\,L$, and calibrate by the method which I have elsewhere * described, and which will appear in the detailed explanation (p. 18). This will give errors at points separating volumes of the capillary equal to that of the calibrating thread, and thus about $\frac{1}{6}\,L$ divisions apart. Plot corrections, *i. e.*, errors with reversed signs, as ordinates and values of U as abscissas, thus beginning plot V., the curve of corrections. Take readings, also, of lengths λ of this thread with lower end l at points distant r, $2\,r$, etc., from the starting-point, A, up to $l = \frac{1}{6}\,L$. Plot points with l as abscissas and of λ as ordinates (plot I.), which will enable us to find the errors between $\frac{1}{6}\,L$ and $\frac{1}{3}\,L$. Separate thread of about r divisions in length, and find lengths λ when set with l at each division, or at intervals of about $\frac{1}{3}\,r$, up to $l = \frac{1}{6}\,L$. Plot values of l and λ (plot II.). Apply method before referred to, finding thus cali-

* Proc. Am. Acad. XVIII., 157; Amer. Jour. Sci., No. 136, 278; Phil. Mag., XIV., 294; Phys. Lab. Notes M. I. T., p. 37 (1885).

bration errors throughout the interval A to $(A + \frac{1}{6} L)$ for points separated by about r. Add to each of these errors its proportionate part of the error already found for the point $\frac{1}{6} L$. Reverse signs, and place results on plot V. Separate thread of $\frac{1}{3} L$, and find λ for $l = A$, $A + r$, $A + 2r$, etc., up to $A + \frac{1}{3} L$. Plot l and λ (plot III.) Separate thread of $\frac{2}{3} L$, and find λ for $l = A$, $A + r$, etc., up to $A + \frac{1}{3} L$. Plot l and λ (plot IV.). The last two plots enable us to find errors between $\frac{1}{3} L$ and $\frac{2}{3} L$, and between $\frac{2}{3} L$ and L, respectively.

The description of the method will now be given in detail by an example, which shows the calibration for each 3° C of a mercurial thermometer, "Baudin, 10521," having a range of 0° to 100° C, and divided to $\frac{1}{5}$ degree. Hence, $L = 100°$, $A = 0°$, and $r = 3°$. The $\frac{1}{50}$th degree was read by eye estimation of tenths of a division, and in most cases without any aid to eliminate the parallax error. The example is not a specially good one to exhibit the accuracy of the method, because the observations are not particularly careful in some parts,— being hastily made,— because the readings are not in all cases taken at exactly the intervals r, $2r$, etc., as herein directed, and because the thermometer has not a uniformly spaced linear scale, but a "normal" scale (*i. e.*, spaced to approximately correct calibration error.) It serves, however, for the purpose of explanation, and very well illustrates another point; viz., that exact correction of a "normal" scale by subsequent calibration is impossible, unless the irregular spacing of the lines is measured and separately allowed for; a requirement impracticable to meet in ordinary work, which should debar such thermometers from refined work. It should be stated that this thermometer was guaranteed by its maker, Baudin, of Paris, to be without calibration error exceeding 0°.04. Inspection of the curve shows the maximum error to be +0°.06 at 35°,—a discrepancy which ought not to be regarded as sensibly exceeding the guarantee.

$\frac{1}{6} L = 16\frac{2}{3}°$ *Thread* — Set thread with lower end at l about 0°, say six times, reading l, and the upper end u as exactly as possible. Then $u - l$ in all cases gives λ, the length which the thread has when its lower end is at l. Set thread six times, with lower end ranging from slightly below to slightly above λ. Set similarly six times each with l covering a short distance on each side of 2λ, 3λ, 4λ, and 5λ, successively. [Number of settings $= 6 \times 6 = 36$]. Be sure that the settings properly overlap. Also take three settings each with $l = 3°, 6°, 9°, 12°, 15°$. [$5 \times 3 = 15$ settings]. For very careful work it is well to extend this subsidiary calibration throughout the tube to get a better knowledge of the quality of the tube. In plot I. the observations shown were not distributed exactly according to above directions.

Plot values of l as abscissas and of $\lambda = u - l$ as ordinates, plotting each separate observation (Plot I.). Draw through points thus obtained a smooth curve according to best judgment, remembering the general rules as to distribution of deviations or accidental errors, and bearing in mind the possibility of local variations in the tube or graduation. Use such a vertical scale that interpolation to the next place of significant figures beyond the last place of the data can be made, this extra place being retained throughout the computations. Use such scale for abscissas that the curve shall not be much steeper than 45° at any point. Dotted curve on plot I., shows irregularity which may be supposed with much probability to be real.

Interpolate on plot I. for $l = 0$ finding $\lambda = 16.692$; then U, the position of the upper end of thread when $l = 0$, is 16.692. Interpolate for $l = 16.692$ finding $\lambda = 16.590$ $\therefore$ $U = 16.692 + 16.590 = 33.282$; for $l = 33.282$, $\lambda = 16.720$ $\therefore$ $U = 50.002$, and so on, as shown in table.

l	λ	U	Comp. U	e at U
0.	16.692	16.692	16.664	+0.028
16.692	.590	33.282	33.328	—0.046
33.282	.720	50.002	49.992	+0.010
50.002	.653	66.655	66.656	—0.001
66.655	.675	83.330	83.320	+0.010
83.330	.655	99.985	99.985	.0

The points U then are readings separating equal volumes of the capillary bore. If the tube were uniform the readings would be $U_2 = 2U_1$, $U_3 = 3U_1$, etc. Assume as calibration unit the volume from 0 to $U_6 = 99.985$. The average length of thread in this distance is $\frac{1}{6}$ (99.985) = 16.664. The error at U_1 will then be $U_1 - 16.664$; at U_2, $U_2 - (2 \times 16.664)$, and so on, as shown in table.

Plot as in V. on same scale as in I., using as abscissas values of U, as ordinates values of e at U with signs reversed. This will then be the beginning of the curve of *corrections*. Points are indicated by cross within circle.

$r° = 3°$ *Thread.*— Separate thread of length about r,— in this case $r = 3°$. Measure λ three times (say) for each degree, *i. e.*, for $l =$ about 0°, 1°, 2°, . . ., 15° ($16 \times 3 = 48$ settings). Work up these

readings (plot II.) exactly as those of $\frac{1}{6}$ *L*, thread just shown, obtaining results shown in first five columns of table.

The error at $U = 16.375$ by interpolation on $\frac{1}{6}$ *L* calibration is found to be $+0.029$. Hence the e' at U should each be increased by its

l	λ	U	Comp. U	e' at U	Propor. part of $+0.029$	Final e at U
0.	3.246	3.246	3.275	-0.029	$+0.006$	-0.023
3.246	3.265	6.511	6.550	-0.039	$+0.012$	-0.027
6.511	3.284	9 795	9.825	-0.030	$+0.018$	-0.013
9.795	3.292	13.087	13.100	-0.013	$+0.024$	$+0.009$
13.087	3 288	16.375	16.375	0.	$+0.029$	$+0.029$

proportionate part of 0.029, *i. e.*, the final error at $U = 3.246$ should be $-0.029 + \frac{1}{6}(0.029)$; at $U = 6.511$ $-0.039 + \frac{2}{6}(0.029)$; and so on, as in columns six and seven. These values of e are then to be plotted with reversed signs along with the values by the former calibration on plot V., thus giving the curve of corrections complete up to 16°.6.

$\frac{1}{6}$ *L Thread — Secondary.*— Interpolate on plot I. now obtaining λ for $l = 3°, 6°, \ldots, 15°$ (as shown in columns one and two below). The corrected length of this thread is already known as 16°.664. If the secondary calibration had been made with another thread than this, its corrected length would be determined by the method described for $\frac{1}{3}$ *L* and $\frac{2}{3}$ *L* later. The errors e_λ in the length of the thread in these various positions $l = 3°$, 6°, etc., is therefore $\lambda - 16.664$, as given in column three. The errors e_l of the tube at l, which are obtained by interpolation on plot

l	λ	$e_\lambda = \lambda - 16.664$	e_l	$e_U = e_\lambda + e_l$.	$U = \lambda + l$
0.	16.692	$+0.028$	0.	$+0.028$	16.7
3	.706	$+0$ 042	-0.020	$+0.022$	19.7
6	.712	$+0.048$	-0.027	$+0.021$	22.7
9	.705	$+0.041$	-0.017	$+0.024$	25.7
12	.630	-0.034	0.000	-0.034	28.6
15	.600	-0.064	$+0.020$	-0.044	31.6

V. and reversing signs are given in column four. Then $e_U = e_\lambda + e_l$ column five, the value of U being $\lambda + l$ as elsewhere is given in the last column. Plot last two columns with proper signs on plot V., thus obtaining complete correction curve to 33°.

$\frac{1}{3}$ L = 33.°3 *Thread.* Separate thread of about $33\frac{1}{3}$°. Measure λ with l = about 0° at least nine times, and then three times each with l = about 3°, 6°, ... , 33° [in all 9 + 11 × 3 = 42 settings]. Plot values of l and λ. Interpolate on plot III. and find λ for l = 0°, 3°, ..., 33° obtaining thus columns one and two of next table. To find the corrected length of this thread, look out on plot V. the correction at 33.678, this being the observed length of thread when l = 0: this correction is found to be + 0.047, so that the corrected length = 33.678 + 0.047 = 33.725. The remaining columns of the table are found similarly to those of the last preceding. Add to plot V. these values of e_U with reversed signs, thus extending curve of corrections to 66°.8.

l	λ	e_λ = λ—33.725	e_l	e_U	U
0.	33.678	—0.047	0.	—0.047	33.7
3.	.700	—0.025	—0.020	—0.045	36.7
6.	.717	—0.008	—0.027	—0.035	39.7
9.	.730	+0.005	—0.017	—0.012	42.7
12.	.713	—0.012	0.000	—0.012	45.7
15.	.693	—0.032	+0.020	—0.012	48.7
18.	.715	—0.010	+0.028	+0.018	51.7
21.	.720	—0.005	+0.029	+0.024	54.7
24.	.735	+0.010	+0.027	+0.037	57.7
27.	.750	+0.025	+0.010	+0.035	60.75
30.	.773	+0.048	—0.040	+0.008	63.8
33.	.787	+0.062	—0.048	+0.014	66.8

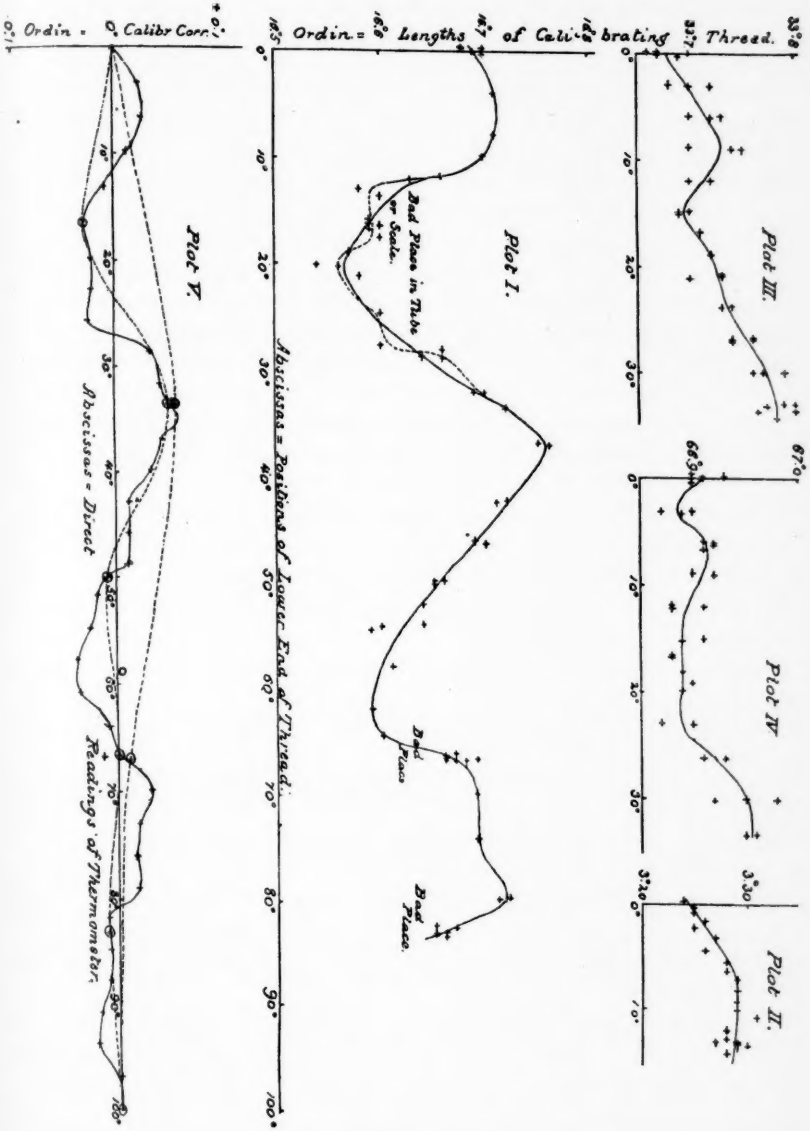
$\frac{2}{3}$ L = 66°.7 *Thread.* Separate thread, and measure λ with l = about 0° at least nine times, and then three times each with l = about 3°, 6°, . . . , 33° [in all 9 + 11 × 3 = 42 settings]. [The errors might readily be

determined up to 167.° with this thread, by continuing the settings up to $l = 100°$, but the result would be less satisfactory than from a using 167 as L from the outset]. Plot values of l and λ. Interpolate on plot IV., and find λ for $l = 0°, 3°, \ldots, 33°$, obtaining thus, columns one and two of next table. To find corrected length of this thread, look out on plot V. the correction at $l = 66°.909$, this being the observed length of the thread when $l = 0°$. This is $+ 0°.001$ $\therefore$ corrected $\lambda = 66.910$. [*A* corrected λ might also be found from the readings when $l = 33°$, but this would be less satisfactory]. The remaining columns of the table are then found similarly to those of the two preceding tables. Add to plot V. these values of ${}^{e}U$ with reversed signs, thus completing the plot for the curve of corrections. A curve through the points thus obtained enables us to find the correction for any reading of the thermometer by interpolation, for we have only to find the ordinate corresponding to that reading taken as abscissa.

l	λ	${}^{e}\lambda = \lambda - 66.910$	${}^{e}l$	${}^{e}U$	U
°					
0	66.909	—0.001	0.	—0.001	66.9
3	.887	—0.023	—0.020	—0.043	69.9
6	.917	+0.007	—0.027	—0.020	72.9
9	.910	0.000	—0.017	—0.017	75.9
12	.890	—0.020	0.000	—0.020	78.9
15	.900	—0.010	+0.020	+0.010	81.9
18	.890	—0.020	+0.028	+0.008	84.9
21	.890	—0.020	+0.029	+0.009	87.9
24	.900	—0.010	+0.027	+0.017	90.9
27	.920	+0.010	+0.010	+0.020	93.9
30	.950	+0 040	—0.040	+0.000	96.9
33	.955	+0.045	—0.048	—0.003	99.95

In plot V. are shown, by points indicated by dot within circle, the results of a separate calibration, using a 33°.3 thread. They check well with the other results. An independent calibration with a 16°.6 thread was subsequently made, and checked at all points within 0°.013, while no single reading on the thermometer can be made much within 0°.02.

ROGERS LABORATORY OF PHYSICS; March, 1887.


Plot III.
Plot IV
Plot II.
Plot I.
Plot V.
Ordin. = Lengths of Calibrating Thread.
Bad Place in Tube
Bad Place
Bad Place.
Abscissas = Positions of Lower End of Thread.
Ordin. = Calibr Corr.
Abscissas = Direct Readings of Thermometer.

THE EFFICIENCY OF SMALL ELECTRO-MOTORS.

BY H. E. H. CLIFFORD, S.B.

Read at a meeting of the American Academy of Arts and Sciences, March 9, 1887.

THE following tests of electro-motors are presented as giving a good example of the efficiency of some of the smaller motors in use at the present day. They have been exclusively devoted to the determination of efficiencies, the subjects of governing and of smoothness of running under different loads being left out of consideration. The only other series of tests which have been published in this country, so far as I have been able to learn, are those made on motors and dynamos at the International Electrical Exhibition held at Philadelphia in 1884.*

The tests have been carried on in the Physical Laboratory of the Massachusetts Institute of Technology, during the years 1885–86, by Messrs. F. A. Pickernell, H. G. Pratt, D. P. Bartlett, and the writer, —students at the Institute.

The number of machines tested was thirteen. I give below their names, together with either a brief description of their peculiarities or a reference to some publication in which they are described.

Griscom (S. P. Thompson's Dynamo-Electric Machinery, 2d Ed., p. 429).

Ayrton & Perry (S. P. Thompson's Dynamo-Electric Machinery, 2d Ed., p. 432).

Gramme-Machine à petite lumière (S. P. Thompson's Dynamo-Electric Machinery, 2d Ed., p. 120).

Magneto Gramme (S. P. Thompson's Dynamo-Electric Machinery, 2d Ed., p. 117).

Thompson (S. P. Thompson's Dynamo-Electric Machinery, 1st Ed., p. 354).

Deprez (Prescott's Dynamo-Electricity, p. 707).

Monarch.—An electro-magnet revolving within a ring-shaped electro-magnet, making use of consequent poles. The ordinary split-ring commutator is used.

Cleveland.— The armature, made up of two shuttle-wound armatures mounted on the same shaft, but placed at right angles to each other. This armature revolves in a strong field produced by two field-magnets,

* Reports of Examiners of Section XXIX., Supplement to the Journal of the Franklin Institute, March, 1886.

wound so as to have consequent poles at their middle. Instead of brushes, four anti-friction rollers are used in connection with a four-part commutator. The pressure of the rollers is adjusted by springs.

Model Edison Dynamo.— A miniature machine of the Edison pattern, but series-wound instead of shunt-wound.

Diehl.— The field-magnets are hinged at the yoke, so that the distance of the pole-pieces from the armature is capable of adjustment. The armatures are made up of two Siemens shuttle-wound armatures at right angles to each other on the same shaft. The motor is shunt-wound. Two sizes were tested.

Hill.— The field-magnets are placed below the armature, which revolves between cast-iron pole pieces. The armature consists of a series of eight spools of wire arranged in couples, the axis of adjacent couples being at right angles to each other. The motor is series wound. Two sizes were tested.

The efficiency of a motor is equal to the horse-power delivered, divided by the rate of consumption of electrical energy by the motor. That is, if HP = horse-power delivered, C = current in ampéres, E = electromotive force in volts, as measured at the terminals of the machine.

$$\text{Efficiency} = \frac{\text{HP}}{\frac{\text{CE}}{746}}$$

The instruments used in the determination of C and E were Sir William Thomson's Current and Potential Galvanometer. These had previously been carefully calibrated, and found to be correct to within 0.2 per cent in the positions at which they were used in the tests. In cases where the compensating magnets had to be used, their intensity was carefully determined on each day of use, so that no material error should be introduced from this source. As far as possible, however, the use of the magnets was avoided.

For measuring the power given out by the smaller motors, a raw-hide belt or a cotton cord was passed completely around a brass pulley on the motor-shaft, the upper end being attached to a spring-balance and the lower to a scale-pan. By varying the weight in the scale-pan the speed of the motor could be changed.

A Chatillon balance weighing to ½ oz. was used. In the tests on the magneto-gramme and the gramme, "à petite lumière," the machines were placed on a cradle dynamometer, a modification of the form de-

vised by Prof. Brackett, of Princeton, and a dynamo machine was used as a friction brake. By closing the circuit of the dynamo through greater or less resistance, the work done, and consequently the power absorbed by the brake, could be varied.

In testing small motors great care must be taken in measuring the speed accurately. In these tests the speed indicator from a small siren was used. This was connected to the motor by an endless band passing from the pulley on the motor-shaft to a pulley of the same diameter on the siren. The power required to run this indicator was excessively slight, and in computing the work done was neglected. The slip of the belt was negligible, as shown by numerous tests. With the magneto and gramme, "à petite lumière" a continuously recording engine-counter was used, connected to the motor by means of a flexible spiral spring.

The following table gives, in parallel columns, the names of the motor tested, the current in ampères, the electromotive force in volts at the motor terminals, the activity in horse-power, the maximum efficiency and the speed for maximum efficiency in revolutions per minute: —

TABLE I.

NAME OF MOTOR.	C.	E. M. F.	H. P.	Maximum efficiency.	Speed.
Griscom	3.94	6.74	.006	17.0%	1400
Ayrton & Perry	14.4	11.1	.082	38.4	831
Gramme "à petite lumière"	5.29	157.6	.945	84.5	2227
Magneto Gramme	12.6	27.4	.138	29.8	2067
Thompson	4.90	8.50	.012	21.7	2370
Deprez	4.74	10.4	.011	16.6	2140
Monarch	4.85	5.78	.004	10.1	578
Cleveland	6.78	12.0	.054	49.8	1360
Model Edison	0.82	90.5	.051	51.4	4065
Diehl, No. 1	7.65	16.5	.021	12.3	4180
Diehl, No. 2	6.12	15.1	.031	24.9	2480
Hill, No. 1	4.77	10.3	.010	14.8	2036
Hill, No. 2	5.04	15.1	.032	31.6	3030

TABLE II.

Revolutions per minute.	Electromotive force in volts.	Current in amperes.	Horse power put in.	Horse power taken out.	Efficiency %
1715	75.8	1.05	.1070	.0278	26.0
1934	75.6	.987	.1000	.0290	29.0
2372	77.4	.942	.0978	.0320	32.7
2414	75.6	.892	.0904	.0306	33.6
2748	75.6	.835	.0846	.0312	36.9
2895	75.6	.807	.0817	.0310	38.0
3085	89.8	.990	.1192	.0462	38.8
3136	76.4	.795	.0814	.0311	38.2
3200	90.2	.960	.1160	.0448	38.6
3234	78.0	.803	.0840	.0328	39.1
3722	76.4	.685	.0702	.0291	41.5
3750	91.9	.890	.1100	.0466	42.6
3957	98.8	.940	.1246	.0544	43.7
3992	91.9	.840	.1035	.0454	43.8
4065	90.5	.820	.0995	.0512	51.4
4284	98.8	.875	.1160	.0533	45.9
4310	90.7	.780	.0948	.0426	45.0
4352	98.6	.850	.1124	.0516	45.9
4860	96.6	.750	.0971	.0437	45.0
4910	98.8	.775	.1027	.0490	47.7
4922	100.0	.812	.1094	.0519	47.5
4975	96.4	.720	.0930	.0399	42.9
5050	95.8	.690	.0886	.0376	42.4
5640	96.0	.690	.0888	.0388	43.7
5870	95.8	.660	.0847	.0365	43.1
6100	95.3	.610	.0779	.0299	38.4
6130	95.9	.630	.0810	.0321	39.7
6206	95.5	.620	.0794	.0315	39.7

The table preceding gives the tests in full made on the Model Edison Dynamo, and illustrates very well the relation of speed and efficiency. This machine is built somewhat after the style of the old Edison Z machine. It is series-wound, and has about the resistance, hot, of an Edison incandescent lamp, old style. The dynamo is an exceedingly neat and smooth-running machine. The motor runs without vibration and with no sparking, and heats up but very little, even at the highest speeds. It has been run for two minutes at a speed of 10,000 revolutions per minute. The great speed here obtained by such simple means, together with the readiness with which it can be varied within wide limits, indicate the availability of such a motor in any physical experiments in which a great speed of revolution is needed, as in studies of the velocity of light, the duration of the electric spark, etc.

TABLE III.

NAME OF MOTOR.	Weight in pounds.	Maximum H. P. delivered.	Horse-power per lb. weight.
Griscom	2.8	.0202	.0072
Ayrton and Perry	39.	.1738	.0045
Gramme "à petite lumière"	172.	1.316	.0077
Magneto Gramme	70.0	.1512	.0022
Thompson	6.3	.0138	.0022
Deprez	9.6	.0138	.0015
Monarch	6.1	.0041	.0007
Cleveland	18.5	.1290	.0032
Model Edison	15.25	.0544	.0036
Diehl, No. 1	9.5	.0209	.0022
Diehl, No. 2	20.0	.0309	.0015
Hill, No. 1	7.0	.0120	.0017
Hill, No. 2	16.0	.0374	.0023

One of the chief advantages derived from the use of electro-motors is the small weight per horse-power developed. The motors, which we have tested with one exception, the Gramme machine, "à petite lumière," have been intended for doing any light work, and the efficiency exhibited

is not, of course, nearly as high as would be shown with larger machines. Activities varying from 1.31 horse-power to .004 horse-power have been obtained, with efficiencies varying from 84.5 per cent to 10.1 per cent. Professors Ayrton and Perry in their paper on "Electro-Motors, and their Government" (Journal Society of Telegraph Engineers, 1883), state that motors may be constructed to deliver one horse-power per one hundred pounds of dead weight. Table III. shows the horse-power per pound weight of the various motors tested, and in no case does it rise as high as 0.01 of a horse-power. Their own motor, as will be seen by referring to the table, gives but 0.0045 of a horse-power per pound of dead weight. In the most efficient machine tested, the horse-power delivered per one hundred pounds dead weight of machine falls a little short of 0.8 of a horse-power. I think that for moderately small motors, about three hundred pounds per horse-power would be a closer figure, although with larger motors this would of course be considerably reduced.

ROGERS LABORATORY OF PHYSICS; March 1887.

ON THE DETERMINATION OF ORGANIC MATTER IN AIR.

BY MARION TALBOT, A.M.

THE determination of the nature of organic matter in air is one of the most difficult problems which can be presented to the chemist, as well as one of the most interesting to the sanitarian.

The methods employed by Dr. R. Angus Smith* were based upon the power of water to absorb organic matter. Dr. Smith also attempted to use a dilute solution of permanganate as an indicator of different degrees of purity of the air; but the presence of other reducing agents than organic matter vitiated the results, and led to the abandonment of the method. It has been revived recently in a modified form by Carnelley and Mackie.†

Dilute sulphuric acid is used as an absorbent in the Observatory of Montsouris.

Mr. E. T. Chapman‡ attempted to modify the process of Wanklyn and Smith for the estimation of ammonia, and apply it to a determination of

* Air and Rain, pp. 399, 421.

† Proceedings of the Royal Society, Vol. xli., p. 238.

‡ Journ. Chem. Soc., 1870, p. 98.

organic matter in air. He used several kinds of absorbers, and finally decided upon pumice-stone as the most efficacious.

The suggestion of Chapman was adopted by Prof. Ira Remsen,* who substituted for the funnel used by Chapman a glass tube,—13 to 18 cm. long and 10 mm. internal diameter. By this means he sought to accomplish two aims,—"To diminish the surface of the absorbing material directly exposed to the air, and to increase the thickness of the mass through which the air was to be passed."

During the past six years, several students at the Massachusetts Institute of Technology have tried to make determinations according to Prof. Remsen's method. The results have been most varied, but in no case completely satisfactory. This experience has served to confirm the last of Prof. Remsen's "general conclusions" in regard to his method. It is stated as follows: "It would be useless to have examinations of air made by any but the most careful workers. It would be time thrown away to have such analyses made by the average practical chemist."

In seeking the causes of the failure, the operation of filling the tube with pumice and transferring it to the flask was found to present serious difficulties. Blank determinations indicated also that mere ignition of the pumice which was used could not be depended upon to secure freedom from organic matter.

The writer made a blank determination, using pumice which had been boiled in permanganate several times and had been standing in permanganate for a year, and was therefore supposed to be entirely free from ammonia. The object was to ascertain if, with this specially prepared pumice and using extreme care, one could perform the necessary manipulation and make the transference without introducing an error. In spite of the precautions taken, ammonia was found in the distillate. The conclusion was, either that, contrary to the supposition, the pumice used was not free from organic matter, or that the mere act of transference resulted in a considerable error. An experiment, showing that a few drops of water trickling over the tip of a finger gave as much free ammonia as several cubic feet of air would give of total ammonia, indicated that inadvertent or incautious handling might prove a serious source of error.

The suggestion was then made to treat the air which was to undergo examination directly with boiling alkaline permanganate, without the intervention of an absorbent, and measure the ammonia in the distillate. The air was made to bubble slowly through the boiling permanganate by means of a platinum tube with minute perforations.

* Bulletin of the National Board of Health, Sept. 11, 1880.

The first point determined was, that no free ammonia escaped condensation. This was shown by passing the air through a U tube containing acidulated water. Although no ammonia was obtained in this U tube it was retained as a part of the apparatus, as the bubbles of air passing through the liquid served as a more delicate measure of the rate of flow and the tightness of the connections than the index of the meter.

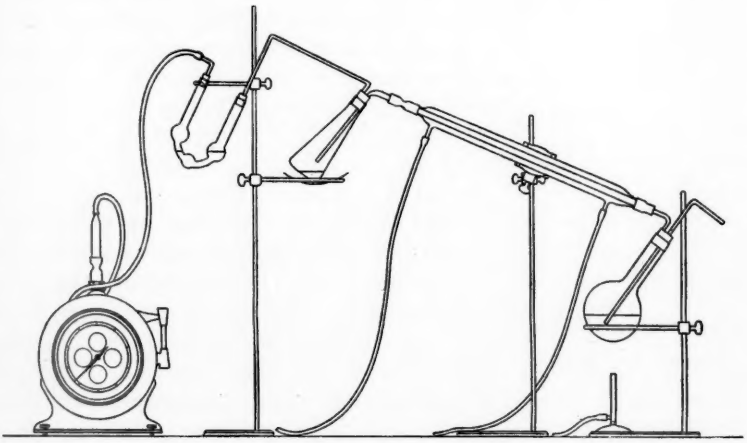
A series of determinations proved that the rate of flow through the permanganate directly affected the results, and two or three cubic feet per hour was generally adopted as the maximum rate.

It was found that the first distillate, on being redistilled, gave an increased amount of ammonia. The conclusion was, that some of the organic matter escaped oxidation in the permanganate, and was retained in the steam which was condensed and collected at various points in the condenser and its connections. It was this fact which led to the adoption of a long, vertical connection between the flask and the condenser. A large proportion of the steam was thus condensed and returned to the flask, bearing with it a certain amount of unconverted organic matter to be acted upon over and over again by the permanganate. In spite of this precaution the process of redistilling was found essential.

Up to this point no step had been taken to ascertain whether all the organic matter was actually retained and converted. In order to decide this important question two sets of apparatus were so arranged that the air examined would pass from one to the other, and be twice subjected to the process of oxidation and distillation. It was somewhat startling, as well as disappointing, to find that the first flask had merely played the part of a coarse filter, the second flask giving half as much ammonia as the first. A logical procedure, but one which was also impracticable, would have been to add set after set of apparatus, until finally the distillate from the last would give no ammonia; but the question at once arose, did the ammonia in the second flask come from the organic matter which had escaped oxidation, or was it introduced by the act of transference of the distillate? Four determinations were made to decide this point. No air was passed through the boiling permanganate, but the process of distillation, transference, and redistillation was carried on just as in preceding experiments. The apparatus was entirely free from ammonia at the beginning of the operation, and at the end the following amounts were obtained: 0.000010 0.000015, 0.000011, 0.000010 mg., or as much as had been obtained from one to two cubic feet of air in previous experiments. The error could

hardly be called constant; indeed, the fact that there was an error led to the inference that it probably could not be constant. The utmost care was used in transferring the condensed liquid back to the flask, but it seemed impossible to prevent minute particles of dust, which had settled upon the lip of the flask, from working their way into the crack between the flask and the cork, and dropping into the permanganate when the tightly fastened cork was removed.

This experiment, discouraging as it seemed at first sight, nevertheless presented, in definite form, the objections to the method as carried out by the writer. They were seen to be transference and redistillation. A simple expedient for removing the difficulty was tried. During the passage of the air the condenser was inclined upward, so that all the steam, as it condensed, returned to the flask containing the boiling permanganate. The tube was thus sealed with condensing steam, and in this way the particles of organic matter which were not completely decomposed at the first passage, were returned again and again to be acted upon by the permanganate. As a check upon this modification the second set of apparatus was again used to receive the air as it emerged from the first set. The result was, that no ammonia was obtained from the second flask, provided the water seal in the first condenser was deep and remained unbroken.



The arrangement of the apparatus is shown in the accompanying sketch. The condenser is replaced in its normal position without breaking the connections for the final distillation.

In spite of the fact that this method avoided the ammonia which was introduced by the transference in the previous experiments, the total ammonia found was much larger than had been before obtained. This was doubtless due to the more complete retention and effectual breaking up of the organic matter.

Sample results of the determinations made are as follows:—

Source of Air.	Amount taken cubic feet.	Rate per hour.	NH_3 gm. per cubic foot.	NH_3 gm. per 1000 cu. meters.
Laboratory	4.3	4.3	0.0000114	0.403
Laboratory, dust raised by sweeping	1.9	2.5	0.0000126	0.445
Lungs	2.	3.	0.0000150	0.530
Body, sifted through clothes . .	1.9	2.1	0.0000105	0.371
External	3.1	1.6	0.0000074	0.261
External (duplicate)	3.05	1.6	0.0000069	0.243

The following figures are given by Professor Remsen, stated in terms of grams per thousand cubic meters:—

External Air.		External Air.	
First experiment	0.343	First experiment	0.154
Second "	0.361	Second "	0.140
Third "	0.449	Third "	0.115
Laboratory Air.		**Laboratory Air.**	
First experiment	0.65	First experiment	0.519
Second "	0.72	Second "	0.495

The slightly increased amount of ammonia obtained from the lungs over that found in the laboratory air, and the still smaller amount in the air from the body, which had been sifted through the clothes, led to the supposition that the suspended matter in air, revealed by the sunbeam, was the principal source of the ammonia. Various kinds of dust were distilled in alkaline permanganate, in order to obtain some idea of the amount of ammonia which they contained. The samples were collected in different rooms at a considerable height, where the finest dust had floated. That taken from a beam fifteen feet high in the Sanitary Laboratory, yielded 0.0000023 gram of ammonia per milligram. Other samples from rooms in houses were collected from the tops of doors and book-cases. The amounts of ammonia obtained were 0.0000130 gram

per milligram, 0.0000185, and 0.0000055,— the last being largely dust from a coal fire. These figures confirmed the supposition that during the course of a determination of the organic matter in air, enough fine dust might settle on the lip of the flask and the cork to seriously vitiate the result.

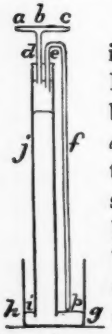
The writer desires to express her indebtedness to Mrs. Ellen H. Richards and Prof. T. M. Drown for suggestions and criticisms.

LABORATORY OF SANITARY CHEMISTRY; April, 1887.

A REGULATOR FOR MAINTAINING CONSTANT EXHAUSTION.

BY S. W. HOLMAN, S.B.

IN an investigation on the transpiration of gases through capillary tubes,* the following problem presented itself: to maintain a constant partial exhaustion in a closed space of about 10 liters capacity, into which a slow, continuous inflow of air or other gas took place; it being also necessary to vary, in separate experiments, the degree of the exhaustion. The apparatus devised to meet these requirements proved satisfactory; and as many occasions arise in physical and chemical work in which this simple device may be of service, the following description is given.



A glass tube *i j*, about an inch in diameter, stands upright in a mercury trough *g h*, two or three inches in diameter. Into the top of *i j* is inserted a rubber stopper with two borings. Through one of these passes one arm of a T joint, *a b c d*, whose other two arms are connected with the aspirator and with the vessel to be exhausted. The latter, if great steadiness is desired, should be several liters in capacity, or be connected with a closed space of at least that volume. Through the other boring passes a tube *e f p*, of one or two millimeters internal diameter, bent twice at right angles, and dipping into the mercury in *h g*. Suppose that the vessel to be exhausted is closed,— the apparatus is available for cases ranging from this condition to a leakage at about half the rate of exhaustion, which can be had through *a*,— and that the exhaustion is begun. As it proceeds, the mercury rises equally in both *j* and *f*, until the mercury

*On the Effect of Temperature on the Viscosity of Gases: Proc. Amer. Acad. Arts and Sci., XXI. 1 (1885).

surface at *h g* becomes somewhat lower than the point *p*. Then the excess of the external atmospheric pressure becomes sufficient to overcome the resistance of the mercury column in *f*; this rises and flows over into the upper part of *j*, falling upon the mercury surface at *j*. This overflow is, of course, followed by an inrush of air through the open point *p*, and a consequent sudden lowering of the mercury in *i j*, and rise in *g f*, thus closing *p*. This first sudden action is followed by others of lessening violence, and a steady condition is soon reached, in which there is a continuous inflow of air and small globules of mercury at *p*, the proportion between the two depending on the relation between the size of the tubes, the capacity of the aspirator, and the supply of gas from the vessel to be exhausted. If a fluctuation occurs in either the rate of aspiration or the supply of gas to be removed, a greater or less proportion of air will be taken in with a corresponding but very small change of pressure within the apparatus. For successful working a proper adjustment of sizes of parts to the work to be done is of course essential, and the final adjustment is made by varying the size of the point *p*, to which the tube *p f* is drawn out. A constriction at some point of *i j* serves to check the violence of the initial fluctuations; and a piece of fine tubing at *c* prevents the too rapid transference of slight fluctuations of the pressure in the top of *j d* to the exhausted vessel. For producing the exhaustion, I made use of the water-jet aspirator* devised by Prof. R. H. Richards, of the Institute.

Tubes *f g* of various lengths, and with the portion at *e* so long that *p* may be considerably raised or lowered by sliding *e* through the stopper at the top of *i j*, render it easy to adjust the regulator to any desired pressure; but where greater range than six inches is desired, it is better to have several tubes *j f*. I have found it possible to maintain constant, within one millimeter, an exhaustion of any amount up to the full action of which the aspirator was capable, although the water-pressure ranged from 15 to 35 pounds per square inch by sudden and irregular jumps. With a water-pressure ranging within the limits of a few pounds, and with an apparatus arranged as described in the paper referred to, I have found it "feasible to keep the pressure constant within a millimeter throughout a whole day's experimenting. The exhaustion during a series of experiments occupying more than half an hour, frequently remained constant within 0.2 or 0.3 mm. In a single experiment a change of 0.2 was rare, the average being under 0.1 mm."

Various modifications will readily suggest themselves to persons using

*Amer. Jour. Sci. [3], VIII., 200; Chem. News, XXXIV., 141; Trans. Inst. Min. Eng., VI., 492 (1879).

the apparatus, by which it may be adapted to special work, and even extended in its application to the case where the internal pressure is in excess of the external.

ROGERS LABORATORY OF PHYSICS; March, 1887.

THE ELEVATED POT-HOLES NEAR SHELBURNE FALLS, MASS.

BY W. O. CROSBY, S.B.

THE occurrence in Buckland, Mass., of well-preserved pot-holes, which were undoubtedly formed at some remote period by the Deerfield River, though they are now nearly seventy-five feet above the level of that stream, has been known for many years. But, so far as I am aware, no one has heretofore determined their geological age, or offered any explanation of their relations to the later geological history of the neighborhood. It appears to me, however, that their situation is rather unique, inasmuch as it affords a key to the demonstration of considerable changes in the geography of that region in comparatively recent times, geologically speaking. I will begin by describing the location of the pot-holes more exactly.

Immediately above the village of Shelburne Falls, the Deerfield River makes a long, sharp bend to the north, passing around a spur of West Mountain; and then its course is comparatively straight, and nearly due west through a broad, open, and approximately level valley for about ten miles, or to the west part of Charlemont. The eastern leg of the great bend measures about one and one-fourth miles, and the western rather more than half a mile; while the dividing ridge is between a quarter and a half mile wide, and rises, at the highest points, which are near the middle of its length, to an estimated height of 250 to 300 feet above the river. The general contours of this ridge are such as to indicate that it is composed mainly or entirely of drift material, but the outlines are deceptive, since distinct outcrops of the solid rocks occur at almost the highest point.

The ridge descends quite abruptly toward the south, to a level estimated at 75 feet above the river; so that at a little distance it appears almost separated from West Mountain, of which it is essentially a continuation. This low gap is utilized by the Fitchburg Railroad, and lies directly on the line which the river would follow if it were to straighten its channel by cutting off the great bend; and that the river has flowed through here at some former time the pot-holes abundantly prove.

In this depression between the ridge and the main mountain, there are extensive outcrops of the underlying gneiss, which has been quarried here, and is also well exposed in the railroad cut. It is in the lowest part of the depression and in the immediate vicinity of the railroad that the pot-holes occur. In fact, many appear to have been destroyed during the construction of the railroad, while many more are probably concealed by the soil. Those that I have seen range from one to four feet or more in depth, and are in a very good state of preservation,— scarcely less perfect than those now forming in the same rock at Shelburne Falls, less than a mile distant.

Taking for granted what every one, upon examination of the evidence, will probably feel obliged to admit, that these pot-holes were formed in the bed of the Deerfield River, the questions arise, when were they formed? and what has been the history of the river before and since? At least three suppositions are possible: —

1. The river may have flowed over the site of the pot-holes prior to the excavation of its present channel, its entire bed in this neighborhood being about 75 feet higher than at present. Some accident, such as a landslide, finally blocked up this ancient channel, and caused the river to flow over the then (we may suppose) somewhat higher gap at the north end of the ridge, where it has continued to flow to the present time.

Several objections might be raised to this hypothesis, but only one need be noticed, since that appears to be fatal. The river is deepening its present channel with extreme slowness. There are comparatively few points where the solid rocks over which the river flows are not protected by loose materials; and these are moved only in seasons of the greatest flood. To lower the bottom of this valley 75 feet would have required an immensely long time, even geologically speaking; a period so extended that ordinary atmospheric action would almost certainly have obliterated the elevated pot-holes, or at least have rendered them very indistinct. Besides, it is certain that the valley has not suffered this amount (75 feet) of erosion since the glacial epoch, and of course the pot-holes could not have survived the action of the ice-sheet. They must be of post-glacial origin.

2. We may suppose that at some former time, perhaps during the melting of the ice-sheet, the volume of the drainage from the basin of the Deerfield was enormously greater than at present; so that the river, although following its modern channel, was yet deep enough to flow over the southern end of the ridge, forming the pot-holes, which, of course, were left high and dry as the flood subsided.

There is nothing to sustain this violent supposition but the pot-holes. Such a vast body of water would choke up the long, tortuous gorge below

Shelburne Falls, converting all the region above into a lake; and, besides, it is impossible that the ice covering such a limited area as the upper Deerfield valley should have melted rapidly enough to make this imaginary torrent a reality. That the melting of an ice-sheet must be a slow process, we may infer from the comparatively inconsiderable floods produced by the melting of snow on a warm day in spring.

3. According to what appears to me to be the true explanation, the river pursued its present course before the glacial period. During the time when this region was buried beneath the ice-cap, its channel, at least around the great bend, was completely filled with detritus, so that after the ice passed away it flowed for some time over the southern end of the ridge, but finally cleared out its original channel, leaving only the pot-holes behind as traces of its temporary divergence. The pot-holes, according to this view, date from the time immediately following the disappearance of the ice-sheet; and although the river has excavated its bed some 75 feet since then, it has been mainly through till, and not through solid rock.

A glance at the map suffices to show that the north-south ridge, previously described, extends directly across the broad valley that lies to the westward; and if this explanation of the pot-holes is correct, then during the time of their formation, the valley, as far west as Charlemont Centre, probably, perhaps farther, must have been a lake. In support of the view that such a lake has existed, may be cited the fact, easily observed by any one passing through the valley, that above this ridge, for eight or ten miles, the valley and its tributaries show at most points a nearly level floor of stratified sand and gravel— modified drift, through which the modern Deerfield has carved its channel, leaving at most points from two to four distinct terraces on either side. The main point, of course, is, that these stratified deposits and terraces are the sediments deposited in the ancient lake.

The elevated pot-holes, then, show us not only that the Deerfield has flowed over their site in post-glacial times, but also that this was the outlet of an extensive but shallow lake, whose existence is confirmed by its own stratified and terraced deposits; and when the river resumed its original channel around the great bend, the lake was drained, and the pot-holes left to mark the brink of the great cataract which must have poured down the eastern slope of the ridge.

MASS. INST. TECHNOLOGY; April, 1887.

USE OF THE ANEROID BAROMETER IN WESTERN MASSACHUSETTS BY THE U. S. GEOLOGICAL SURVEY.

BY LOUIS F. CUTTER, S.B.

THE topographical work of the U.S. Geological Survey in Massachusetts is done in three different ways in different parts of the State. In the southeastern part, where there is but little relief, and where the land is in great measure covered with woods, the traversing of the roads has been relied on for topographic detail, and the traverses are controlled by a few points located by triangulation. Around Boston and in the northeast part of the State, the plane-table has been used for the tertiary triangulation, and the roads have been traversed, the chief part of the detail being put in from the roads. In the hilly country west of the Connecticut, hardly any traversing is done: the plane-table is used for triangulation and detail. I intend to describe the barometric method used last summer in Western Massachusetts; but in order to do so it will be necessary to roughly outline the whole plan of work.

The Massachusetts map is to be published on a scale of 1: 62500, or about one mile to the inch. For convenience and accuracy the manuscript maps are made on a scale of 1:30000. The published atlas-sheets will each cover 15′ of latitude and 15′ of longitude,— or about 17 miles from north to south, and 13 miles from east to west; but as a plane-table sheet representing this area on a scale of 1:30000 would be unwieldy, the northern and southern halves of each atlas-sheet are surveyed on separate plane-table sheets, so that each plane-table sheet represents an area of about $8\frac{1}{2}$ by 13 miles. The contour interval is 20 feet on the manuscript maps, but in the hilly country it will be increased to 40 feet for publication.

The triangulation points on which the plane-table triangulation is based, are those of the Borden State Survey (1838), and of the Coast Survey. There are generally not more than two on each sheet.

Last season the plane-table division consisted of six plane-table sub-parties, under the charge of W. D. Johnson. Each sub-party was supplied with a horse, and consisted of two men, and to each was assigned a plane-table sheet. The duty of one man was to plan the work and to run the table. The other man acted as his assistant, and was not in all cases a trained topographer. Sometimes the assistant was hired from the neighborhood. His duties were to carry things, to drive and feed the horse, to help erect signals, and, if he was competent, to read the aneroid and work up vertical angles.

The plane-table was used as a triangulating instrument almost exclusively: no telemeter was used. Distances were measured, when it was neces-

sary, by counting the revolutions of the wagon wheel, or by pacing. The detail of the roads was obtained from the old town maps, which were originally made by traversing the roads. These roads were put upon the new map in short pieces, say from $\frac{1}{4}$ mile to 2 miles, between objects such as houses or roadside trees, which were located by plane-table intersection. Tangents were also drawn on the plane-table sheet to bends in the roads, and single lines to road-corners were often useful even when no intersecting line could be drawn. The different town maps varied greatly in accuracy, but in all cases they received a thorough revision. The topographer drove over each road, and made corrections where he found mistakes, and crossed off all abandoned roads and houses, and put on the new houses, and saw that each house was shown at the right distance from the road. For the purpose of making these corrections, the town maps were copied on a scale of 1:30000, and the copies were carried on a lap-board. In driving over the roads, barometer-readings were taken at all prominent changes of slope, say about six to the mile, on an average, and approximate contour lines were sketched as far on each side of the road as the shape of the land could be easily seen from the wagon. This would average perhaps $\frac{1}{2}$ mile on each side. The wood-outlines and brooks were sketched as far as their position could be well estimated. Sketching was of course done also at plane-table stations on the plane-table sheet.

The following is a sample of the notes of a side excursion made by an assistant: —

TUESDAY, SEPT. 21.	Aneroid reading.	Elevation.
Huntington flag (sta.)	2783	*+1330+
Col. S.	2717	1266
Leg Hill.	2741	1294
Col. bet. Leg Hill and Tob.	2612	1166
Huntington flag again (sta.)	2773	+1330+

*+ + denotes a vertical angle elevation.

The hypsometry was based on the trigonometric elevations of the Borden points. Differences of elevation between located points were found by means of vertical angles taken with the alidade, the horizontal distance being measured with a scale on the plane-table sheet. The elevations of points near plane-table stations were determined by the aneroid barometer. The assistant took readings, first at the station, then at the various valleys, humps, cols, and other prominent points near by, according to the direc-

tions of the plane-table man, and then at the station again. The Airy scale of feet was used, and corrections for temperature of the air were not often made, as the differences of elevation were usually small. If on returning to the station a change of pressure had taken place, it was assumed to have taken place uniformly as regards time, and therefore approximately as regards distance walked.

Sometimes readings were taken in going from one station to another, in which case the same assumption was made.

The chief part of the barometric work, however, was done in the course of the road-sketching, as the sketching on the town maps is called. Enough points along the roads were determined in elevation by vertical angles, to insure readings on determined points at short intervals of time. It was very seldom that two hours elapsed during road-sketching without a reading at a vertical angle-point.* The readings were usually written on the town map at the place of observation ; and if at different times it happened that several readings were taken at the same point, all readings after the first were written in a list on the margin, each such point being given a name by which it could be remembered. On some rainy days the readings were written out in a note-book in the following form.

Columns E and A are the only ones that are taken from the town-map sketch. The numbers under A are the aneroid readings, and under E are written the names of the places where the readings were taken. When the vertical angles are worked up, the real elevation of each vertical angle point is written with red ink in column B, opposite the name of the point ; then each red-ink elevation is subtracted from the corresponding aneroid reading, and the difference is written in column C.

If the temperature of the air were always 50° F. (for which temperature the Airy scale is correct), and if the pressure at each level remained the same throughout the day all over the country sketched, and the aneroid made no errors in indicating the pressure, all these differences would be equal. If they are not equal, their variation indicates approximately the fluctuations which would have been observed in a stationary barometer read at intervals of from ten minutes to two hours throughout the day. If points were plotted with the differences taken from column C for ordinates, and times of observation for abscissæ, an inverted barographic curve could be drawn through them. The ordinates to the curve at intervening points would be approximately the differences at intervening times, and by subtracting from each intervening barometer-reading the ordinate to the curve for the time at which that reading was made, the elevation of the point of observation would be found.

* I describe here the method used in the sub-party of which I had charge. In the other sub-parties the details of keeping and working up the notes were different.

TABLE I. FORM OF NOTES (copied from note-book).

SEPTEMBER 18, 1886.—AFTERNOON. PLACE.	A—B	RESULT OF SINGLE OBSERVATION.	ANEROID READING.	FINALLY ACCEPTED. ELEVATION. +375+ VERTICAL ANGLE ELEVATION. —375— WEIGHTED MEAN OF SEVERAL RESULTS. 375 RESULT OF SINGLE OBSERVATION.
E	C	D	A	B
Bassett's Little Flag	170		2100	+930+
Pinnacle near house			2107	936
Bend to L. one fourth mile beyond			2175	1003
Town line			2193	1020
Pinnacle of Fame			2230	1055
Brook opposite			2150	975
Pinnacle of Fame again			2230	1055
False Pinnacle			2264	1088
True Pinnacle			2281	1105
Red House			2255	1082
Elm Corner	177	1101	2280	—1103—
First valley on road S.W.			2243	1065
Large white house (Poplar)			2287	+1106+
Valley			2233	1052
Big Shabby			2295	1115
Elm Corner again	177	1099 / 1101	2280	—1103—
Second bend to L. on road N.E.			2305	1133
Tie-Rod Corner	168	1193	2365	—1197—
Mail-Box Corner	170	1248	2423	—1253—
Brook east			2374	1204
Pinnacle			2417	1247
Runaway Bog			2347	1177
Huntington Flag	170		2500	+1330+
Ten feet below White House, A	174		2367	+1193+
Prospect Corner			2305	1130
Butternut Bridge	178	1009	2185	—1007—
Brook crossing on road to S.			2096	918
Brook one half mile farther S.			2000	821
Brook opposite sharp bend to L.			1900	720
Brook crossing			1895	714
Pineapple Corner	181	749	1925	—744—
White S. H. Corner		755	1935	—754—
Lyman's	177		1777	+600+

EXPLANATORY REMARKS.—In column B, +999+ denotes an elevation obtained by vertical angle. In column B, —999— denotes the weighted mean of the results of several aneroid observations. 999 denotes the result of one aneroid observation.

The time occupied in making these observations and doing the sketching was about three and one-half hours, and the length of road sketched was about six miles.

In practice it is not necessary to plot the points and draw the curve, for the fluctuations are generally so slight and so nearly uniform that they can be carried in the head, and it is usually sufficiently accurate to consider the difference as varying uniformly between observations at vertical angle points. It is not necessary to note the time of each observation, for differences of time are approximately proportional to distances traveled, and when there is a delay the topographer can remember it and allow for it.

It usually happens that between two readings at red-ink elevations, a

reading is taken at some point, most often a road-corner or cross road, where other observations have been made, possibly on different days. In working up the notes, the elevation of such a point is found first, by the method just described, and the result is written in column D. Then the notes are searched for other observations at the same place, and each of them is worked up in the same way, and its result written under D. The mean of all the results, weighted according to the judgment of the observer, is written with blue ink in column B. The blue-ink elevations are then used, in the computation of the remaining elevations, exactly as the red-ink elevations which are written in column B as soon as found. In Table I, red ink is denoted thus, + 1887 + and blue ink thus, — 1887 —.

In the example there given the height of Elm Corner was first found, by subtracting from the reading at that place the difference 177, interpolated between a difference of 170 at Bassett's Little Flag, and the difference of 181 at Poplar House. The remainder, 1101, was written in column D. Then the difference of elevation between Elm Corner and Poplar House was found from the two readings at Elm Corner and the intermediate one at Poplar House. The result was seven feet; and by subtracting this from + 1106 +, which is the elevation of Poplar House, an elevation of 1099 was found for Elm Corner. Then by interpolating between Poplar House and Huntington Flag, the figure 1101 was obtained for Elm. An observation on a subsequent day gave 1108 for the same place; — 1103 — was decided on as the most probable elevation, and was written in blue opposite each of the three observations.

Mail-box Corner was then worked up between Elm Corner and Huntington Flag, and the result averaged with the results obtained from four other observations made on different days. The result was — 1253 —, giving a difference of 170. The elevation 1193 for Tie-rod Corner, in column D, was found by interpolating a difference between 177 at Elm Corner and 170 at Mail-box Corner. The difference thus found was 172; and subtracting this from 2365, the reading at Tie-rod, 1193 was obtained for the elevation of that place, and was written in column D. This being averaged with two other results afterward obtained, — 1197 — was accepted and written in blue.

The chief advantages of taking barometer-readings along the roads are: —

1. Reasonably accurate elevations are found at short intervals on the roads,— where lack of accuracy would be most felt by those who are to use the map.

2. Cheapness. It is necessary to drive over the roads to correct mis-

takes in the town maps, and to sketch the natural features. The barometer-readings take but little additional time, while leveling would take a great deal.

The advantage in the method of taking frequent readings at known elevation, is, that it does away with the expense of observing a base barometer.

The advantages of the special method here described — that of using averages of aneroid elevations as well as vertical angle elevations for adjusting intermediate readings — are as follows: —

1. Check-points are established at short intervals, and in more convenient places than would be possible without great expense by vertical angles.

2. Time is saved on stations, because it is not necessary to take so many vertical angles as would otherwise be required. Sometimes the necessity of making an extra station is avoided.

The chief disadvantage of this special method is, that a good many observations have to be made before any of them can be finally adjusted.

The chief sources of error in the results of single observations adjusted between two determined elevations are as follows: —

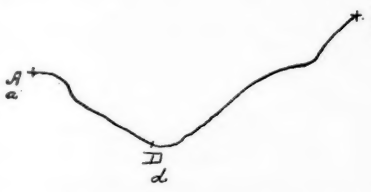
1. Instrumental errors of the aneroid. The most important ones are I think, (*a*) error due to shocks; (*b*) slowness; (*c*) temperature errors, including those due to unequal heating or cooling of different parts of the instrument; (*d*) graduation errors. The effect of the slow change of zero point is, of course, eliminated by the method of adjustment between known elevations.

2. Wrong assumption of the barographic curve. This can be avoided only by making the readings at check-points very frequent.

3. Local disturbances of pressure caused by the wind where it is obstructed by hills, houses, trees, etc., or by the body of the observer, or by the aneroid itself. This is probably a very serious cause of error: readings of an aneroid held in different positions with reference to the direction of the wind, often differ as much as ten feet; and a member of Mr. Johnson's party once found a difference of about forty feet between the readings of an aneroid held first to one side and then to the other side of his body. The mean of the readings to windward and to leeward of the body is sometimes accepted with a view to getting rid of a part of the error, but the effect of the local disturbance caused by hills, houses, etc., cannot be eliminated in this way.

4. Errors due to a wrong assumption of the air temperature. I very seldom applied the correction for the departure of the air temperature from 50° F., because it happened that when large differences of elevation were

to be measured the temperature was generally about 50°. The correction may be made, when it is necessary, in the following way: —



ADB represents the profile of a piece of road which is driven over from *A* to *B*. The elevations at *A* and *B* are known, but that at *D* is unknown.

Let A = the elevation at A; B = the elevation at B; D = the elevation (unknown) at D; a = barometer-reading at A; b = barometer-reading at B; d = the barometer-reading at D; α = difference at $A = a - A$; β = difference at $B = b - B$; δ = (unknown) $d - D$; δ' = the difference which would have been assumed for D if temperature did not have to be taken into account; $\delta' = \alpha + \varepsilon\gamma$; γ = the increase of difference in going from A to $B = \beta - \alpha$; γ' = that part of the increase of difference encountered in going from A to B, which is due to the change of pressure on a level; θ = the excess of the temperature above 50° F.; γ'' = that part of the increase of difference encountered in going from A to B, which is due to the departure of the air-temperature from 50°.

$$B - A = (b - a - \gamma')\left(1 - \frac{\theta}{500}\right) \text{ by Airy's formula;}$$

$$\text{but } B - A = (b - a - \gamma)$$

$$\therefore \quad \theta = \gamma - \gamma' - \frac{\theta}{500}(b - a - \gamma')$$

$$\gamma'' = \gamma - \gamma' = (b - a - \gamma')\frac{\theta}{500}$$

In going from A to D, the increase of difference due to the change of pressure on a level is $\varepsilon\gamma'$, where ε is a ratio assumed from what seems to be the probable shape of the barographic curve, and the increase of difference due to θ is $(d - a - \varepsilon\gamma')\frac{\theta}{500} = \frac{d - a - \varepsilon\gamma'}{b - a - \gamma'} \cdot \gamma''$.

The total increase of difference in going from A to D is

$$\delta - \alpha = \varepsilon\gamma' + \frac{d - a - \varepsilon\gamma'}{b - a - \gamma'} \cdot \gamma''.$$

If the elevation of D is such that $\frac{d - a}{b - a} = \varepsilon$, then $\frac{d - a - \varepsilon\gamma'}{b - a - \gamma'}$ will also be equal to ε, and $\delta - \alpha$ will be equal to $\varepsilon(\gamma' + \gamma'') = \varepsilon\gamma$. δ, which is the true difference at D, will be $\alpha + \varepsilon\gamma = \delta'$, which is the difference which would have been assumed if temperature did not have to be taken into account. $d - \delta'$ gives the true elevation of D, just as it would if θ were 0.

If D is not such as to make $\frac{d-a}{b-a} = \varepsilon$, we can assume a barometer-reading, d', such that $\frac{d'-a}{b-a} = \varepsilon$. Then $d' - \delta'$ gives the elevation (D') of the point where the barometer would read d' at the same time that the barometer at D was reading d. Then

$$D' - D = (d' - d)\left(1 - \frac{\theta}{500}\right)$$
$$d' - \delta' - D = (d' - d)\left(1 - \frac{\theta}{500}\right)$$
$$\therefore D = d - \delta' + (d' - d)\frac{\theta}{500}$$
$$\delta = d - D = \delta' - (d' - d)\frac{\theta}{500}$$

Hence the rule:—

1. Assume δ'.
2. Make d' such that $\frac{d'-a}{b-a} = \frac{\delta'-a}{\beta-a}$. This may rapidly be done mentally with sufficient accuracy.
3. For each 5° *F.*, by which the air temperature exceeds 50° *F.*, subtract from δ' one per cent of $(d'-d)$: the result will be δ'.
4. $d - \delta = D$, the elevation sought.

Unless $d'-d$ is very large, the temperature may be estimated with sufficient accuracy by the feeling of the air.

The material in the note-book gives two ways of judging of the reliability of a single observation.

1. If a red-ink elevation should be supposed to be unknown, and should be computed by adjusting between the two adjacent red-ink elevations, the difference between the computed elevation and the vertical angle elevation would be an error that might be expected in the result of any single observation adjusted between two observations at known elevations, made at an equal interval of time; and if a large number of known elevations should be worked up in this way, care being taken to exclude those cases where the interval of time between the observations at alternate vertical angle points was too long, a very fair notion of the average and maximum errors of the results of single observations in the actual work might be obtained. This has not yet been done.

2. If there is no common source of error, a comparison of the results of the several observations at the same point, with the accepted mean, will give some notion of the trustworthiness or untrustworthiness of the results of single observations. Such a comparison is made in Table II., which comprises all the results available at the time of writing. The table explains itself.

TABLE II. DEVIATIONS.

	Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.		Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.
Mail-Box Corner . .	1253	2.2	1253	0		Worthington X Roads	1322	1.7	1318	4	
		5	1248	5				4	1322	0	
			1255	2					1323	1	
			1252	1							
			1256	3							
Littleville Bridge .	506	12.2	499	7	A long time elapsed between readings on vertical angle points.	House near Abbot .	1236	1.3	1235	1	
		24	530	24					1235	1	
			515	9					1238	2	
			497	9				2			
Wheel Corner . . .	448	5.3	448	0		Gate Corner . . .	1222	1.0	1225	3	
			453	5				3	1222	0	
		8	440	8					1222	0	
			445	3							
Butternut Bridge . .	1007	8.0	1008	1		Poverty S. H. . . .	312	2.0	310	2	
			1009	2					310	2	
			1011	4				2	314	2	
		25	982	25							
Water Corner . . .	580	2.2	583	3		Skunk X Roads . .	468	6.0	468	0	
			581	1				14	454	14	
			579	1					472	4	
		4	576	4							
Green House . . .	551	1.5	548	3		Gingerbread . . .	300	12.7	275	25	About two hours between readings on vertical angle points.
		3	554	3				25	308	8	
			551	0					305	5	
			551	0							
Ford	582	7.5	573	9		Station	295	12.0	313	18	
		12	594	12				18	287	8	
			557	5					285	10	
			586	4							

TABLE II. DEVIATIONS — *Continued.*

	Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.		Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.
Pond Brook Bridge .	503	8.2	503	0		Bar-Room X Roads	305	7.0	314	9	
		3	506	3					304	1	
			500	3				11	294	11	
Iron Bridge	527	11.0	525	2		Yellow Corner . .	288	7.3	287	1	
			535	8	Fierce gusty wind, with rapidly falling barometer.				280	8	
		23	504	23				13	301	13	
Windy Corner . . .	1180	7.7	1184	4		Connecticut Corner	307	8.3	298	9	
			1171	9					304	3	
		10	1170	10				13	320	13	
Dayville Bridge . .	577	15.3	587	10		Blue-Curtain Corner	332	2.7	335	3	
			591	14	About three hours between readings on vertical angle points.			3	335	3	
		22	555	22					330	2	
N. Chester Bridge .	723	9.7	737	14		Red S. H.	1244	4.3	1248	4	
		14	721	2					1241	3	
			710	13				6	1237	6	
Sunset Corner . . .	1572	6.3	1572	0		Lone House . . .	1253	1.7	1248	5	
			1566	6				5	1253	0	
		13	1585	13					1253	0	
Bass-Hill Corner . .	1624	8.7	1628	4		Round-Tree House .	1028	6.0	1034	6	
			1616	8					1024	4	
		14	1638	14				8	1020	8	
Swamp Corner . . .	1379	5.0	1380	1		Saw-Mill Corner .	528	4.0	522	6	
		13	1366	13				6	531	3	
			1380	1					525	3	
Lightning-Rod Corner	1558	3.3	1557	1		Pecooler Place . .	636	8.7	630	6	
			1559	1				14	650	14	
		8	1550	8					642	6	

TABLE II. DEVIATIONS — *Continued.*

	Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.		Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.
Red-House Corner .	1340	0.3	1340	0		Shanty Corner . .	845	2.3	847	2	
			1340	0				3	842	3	
		1	1341	1					847	2	
Maple Corner . . .	1150	5.0	1156	6		White S. H. . . .	754	0.7	753	1	
		6	1145	5				1	755	1	
			1146	4					754	0	
Elm Corner	1103	3.0	1101	2		Roaring Brook Bridge	411	2.5	413	2	
			1101	2				3	408	3	
		5	1108	5							
						Spruce Corner . .	335	16.0	346	11	
								21	314	21	Very windy.
Tie-Rod Corner . .	1197	4.0	1193	4		Springfield Corner .	316	6.5	327	11	
		7	1204	7				11	314	2	
			1198	1							
						Brook Triangle . .	300	17.0	312	12	
								22	278	22	Very windy.
P. O. Corner	1238	1.5	1237	1		Snake-Fence Corner	308	1.0	307	1	
		2	1240	2				1	309	1	
Ruin Corner	1470	3.5	1475	5		R. R. at Basalt Crossing	280	5.0	275	5	
		5	1468	2				5	285	5	
Red-House Corner .	1503	2.0	1501	2		K. Corner	403	8.0	407	4	
		3	1506	3				12	391	12	
Grass Corner . . .	1429	2.0	1430	1		Upper J.	490	11.5	500	10	
		2	1426	3				13	477	13	
Maple Hitch	1510	2.0	1508	2		Talkative Corner .	456	12.5	447	9	
		2	1512	2				16	472	16	

TABLE II. DEVIATIONS — *Continued.*

	Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.		Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	REMARKS.
Wrought-Iron Bridge	672	5.5 8	664 675	8 3		Cut-off Corner . .	278	0.5 1	279 278	1 0	
Littleville Corner . .	1142	3.0 3	1139 1145	3 3		T. Corner	423	3.0 3	420 420	3 3	
Graveyard Corner .	1104	2.5 4	1105 1100	1 4		Talkative Brook . .	315	0.0 0	315 315	0 0	
Ash Hitch	782	1.0 2	782 784	0 2		Tavern Corner . .	297	0.0 0	297 297	0 0	
Secluded H. Corner .	773	1.0 1	772 774	1 1		Plowed-Field Corner	422	16.5 17	438 405	16 17	
Pasture Flag . . .	827	11.5 12	838 815	11 12		Terrace Corner . .	318	3.0 4	314 320	4 2	
Goss Hill Corner . .	704	2.5 4	703 708	1 4		Still Corner . . .	293	7.0 7	300 286	7 7	
X Road Bridge . .	724	1.0 1	723 725	1 1		South Sodom Corner	328	5.0 5	333 323	5 5	
X Road in Norwich Village	1083	5.0 7	1080 1090	3 7		White-Oak Corner .	316	1.5 2	317 314	1 2	
S. H. Bridge . . .	870	3.5 4	874 867	4 3		North Road Corner	1272	4.0 5	1275 1267	3 5	
Discouragement Bridge	860	35.5 36	895 824	35 36	Very windy. Long time between check readings.	Little River Bridge	546	3.0 6	540 546	6 0	
Timothy Corner . .	1212	0.5 1	1212 1213	0 1		Culvert Corner . .	1170	16.0 23	1161 1193	9 23	Nothing remarkable.

TABLE II. DEVIATIONS — *Continued.*

	WEIGHTED MEAN.	AVERAGE AND MAXIMUM DEVIATION.	RESULTS OF SINGLE OBSERVATIONS.	DEVIATION FROM WEIGHTED MEAN.	REMARKS.		WEIGHTED MEAN.	AVERAGE AND MAXIMUM DEVIATION.	RESULTS OF SINGLE OBSERVATIONS.	DEVIATION FROM WEIGHTED MEAN.	REMARKS.
Perplexity Corner .	1562	2.5 3	1565 1560	3 2		Friday Corner . .	1325	6.5 8	1330 1317	5 8	
Ridge Corner . . .	1450	5.0 7	1457 1447	7 3		L. Corner	1250	1.5 2	1249 1248	1 2	
T. Hill Split	1365	3.5 5	1363 1370	2 5		Wood Corner . . .	905	3.5 4	902 909	3 4	
Big Brook Corner .	1120	5.0 6	1114 1124	6 4		Root House . . .	1090	3.0 4	1086 1092	4 2	
Becket Bridge . . .	784	0.0 0	784 784	0 0		Emergency Corner .	555	2.5 3	557 552	2 3	
Bow Corner	1128	0.5 1	1127 1128	1 0		Red-House Corner .	478	1.0 1	479 477	1 1	
Half and Half Corner	1400	6.5 11	1389 1402	11 2		Locust Corner . .	784	2.5 4	785 780	1 4	
Ringville Common .	1135	3.5 5	1130 1137	5 2		House below Dinner Place	1067	10.0 10	1057 1077	10 10	
Remembrance Corner	1130	0.0 0	1130 1130	0 0		Red-Roof Church .	452	3.0 3	455 449	3 3	
No Sign Corner . .	1347	3.0 3	1344 1350	3 3		Pineapple Corner .	744	4.5 5	740 749	4 5	
Slippery Bridge . .	1234	0.5 1	1233 1234	1 0		Grapevine Corner .	833	2.5 3	835 830	2 3	
Yellow X Road . .	1475	0.5 1	1474 1475	1 0		Triangle Corner . .	727	3.5 6	721 729	6 1	

TABLE II. Deviations — *Continued.*

	Weighted Mean.	Average and Maximum Deviation.	Results of Single Observations.	Deviation from Weighted Mean.	Remarks.
Lilac Corner	1523	0.0 0	1523 1523	0 0	
S. Corner	1134	0.0 0	1134 1134	0 0	
Johnny Sis Bridge	494	5.5 10.	495 484	1 10	
New Barn Corner	1470	9.5 10	1479 1460	9 10	
N. E. S. H.	654	0.5 1	654 653	0 1	
Round-Tree Corner	868	2.0 2	866 870	2 2	
Sumach Corner	936	5.0 6	940 930	4 6	
Bridge below Mill Pond	1064	4.0 6	1066 1058	2 6	
Massasoit House	1179	9.0 9	1188 1170	9 9	
Opposite Kidd's	1478	18.0 35	1513 1477	35 1	Rapidly falling barometer—long time between checks.
Bridge at One-House Corner	905	12.0 13	894 918	11 13	
Red-Mill Bridge	1033	14.0 23	1038 1010	5 23	Long time between checks.

Number of Observations 270

Average of all Deviations 5.26

Five Deviations greater than 24, in order of Magnitude 36, 35, 35, 25, 25

Magnitude of Deviations.	Number of Deviations.	Per cent of Whole Number of Deviations.
Greater than 39.	None.	0.0
35 to 39 inches.	3	1.1
30 to 34 inches.	None.	0.0
25 to 29 inches.	2	0.7
20 to 24 inches.	7	2.6
15 to 19 inches.	4	1.5
10 to 14 inches.	31	11.5
5 to 9 inches.	55	20.4
0 to 4 inches.	168	62.2
Total	270	100.0

The average *error* of the results of single observations is probably considerably greater than the average deviation would indicate, for there are three sources of error common to all the observations at some of the points.

1. If the several results for the same point are adjusted between the same two blue-ink elevations, the results will have in common the error of the blue-ink elevations.

2. If the pressure is the same, or nearly the same, when the several readings at one point are taken, a graduation error in the part of the scale to which the needle points will similarly affect all the results.

3. If the several observations are made on the same day between the same two known elevations, a wrong estimation of temperature will produce equal errors in the results.

If a good instrument is used, the first and last causes are probably the only ones that largely increase the error of the mean; and these do not have so much effect as might be supposed, because in the great majority of cases the difference of elevation is small, and because in some cases the different observations at secondary blue-ink points were adjusted between different pairs of determined elevations. This, of course, happens sometimes at cross roads and road corners.

An examination of the maximum deviations is likely to be more profitable than a study of the averages, because it may bring out the causes of large errors. In the foregoing table, remarks as to the state of the weather, and the length of time which elapsed between the readings at determined points have been placed opposite each deviation greater than 20 feet. There are 11 such deviations, and they may be classified as follows: —

4 (35, 21, 22, and 23)— very windy.

6 (24, 22, 25, 36, 25, 35)— long time between check-readings (in the last one [35] the pressure was very rapidly falling).

1 (23) nothing remarkable in the weather so far as could be seen or felt, but a comparison of readings taken at short intervals of time on vertical angle points a short time before the observation in question, discloses the fact that the pressure was fluctuating with extraordinary rapidity.

As was to be expected, close agreements were sometimes obtained when the conditions were apparently as unfavorable as in the foregoing examples.

The examination of the large deviations seems to indicate that the large errors are caused by:

1. The local effect of the wind.
2. The departure of the two barographic curves from the assumed one.

The inference seems to be that when single readings must be depended on, and occasional errors of more than 25 feet are not allowable, the time between readings at determined points should not exceed, say, $\frac{3}{4}$ to $1\frac{1}{4}$ hours, and very windy days should not be used for barometric work.

It has been proposed to use next summer a stationary aneroid barograph to record the fluctuations of pressure during the day, and so avoid the errors due to a wrong assumption of the barographic curve, and render unnecessary such frequent readings at determined elevations.

U. S. GEOLOGICAL SURVEY, WASHINGTON, D. C.; April, 1887.

ON THE DETERMINATION OF NITRATES IN POTABLE WATERS, BY GRANDVAL AND LAJOUX'S PROCESS.

BY FREDERICK FOX, JR., S.M.

THERE appeared in the *Comptes Rendus*, July 6, 1885, the account of a new method, by MM. Grandval and Lajoux, for the determination of nitrates and nitrites in potable waters and in air. This method is based upon the following facts: When a nitrate or nitrite is treated with a mixture of phenol and sulphuric acid monohydrate a chemical change takes place, and a certain amount of picric acid is formed, depending upon the amount of nitrate or nitrite used, for the phenol is always present in excess. By the addition of an excess of ammonium hydrate ammonium picrate is formed, which gives a yellow color to the liquid. This color can be matched by employing the right amount of a standard potassium nitrate solution, and subjecting it to the same process.

For the determination 10 c.c. of the water to be analyzed are evaporated to dryness in a small porcelain dish on the water bath, a few drops of the sulphophenic acid added to the cold residue, and well rubbed over all parts of it, then water, and finally an excess of ammonium hydrate. The liquid is poured into a Nessler tube, and its color matched by a known amount of the standard nitrate solution.

This solution, as used by the originators of the method, contains 0.936 grm. of potassium nitrate per litre of water, equivalent to .0005 grm. nitrogen pentoxide, N_2O_5, in 1 c.c. The sulphophenic acid is made by adding to 37 grms. of sulphuric acid monohydrate 0.3 grm. of phenol.

The process has been used in the Laboratory of Sanitary Chemistry for some time, with good results, with waters containing about 1 part of N_2O_5 in 100,000. Mr. C. G. Merrill found, that in a water free from organic

matter the presence of .000005 grm. could be detected. Organic matter present in a water which contains but traces of nitrates or nitrites, will interfere with the delicacy of the test, since a different shade of color results, which runs into a brown instead of a yellow, and thus hides the latter. It was found that at least .0025 grm. of the nitrate was required to overcome the brown shade produced by the organic matter in 10 c.c. of Cochituate sufficiently well to permit the accurate estimation of the depth of the yellow color.

In a series of experiments made by Mrs. Ellen H. Richards to determine the delicacy of the test, it was discovered that during evaporation a portion of the nitrate is lost. This is particularly noticeable during the concentration of dilute solutions; indeed, the greater the bulk evaporated, the greater the loss, until a point may be reached when no color at all is obtained on treating the residue with the acid and alkali in the customary manner.

It has long been known that certain salts in solution, when boiled, are decomposed. Fittig (Ann. Chem. Pharm., 128, 189) has proved this to be true of ammonium chloride. Debbits (Ber. 5, 820) found that all ammonium salts will lose some of their ammonia when their solutions are boiled, and also when a current of an inert gas, as nitrogen, is passed through a cold saturated solution. A. R. Leeds (Am. J. Sci. III., 1874, 7) states that nitrates will, in like manner, give up a portion of their acid at temperatures far below those commonly regarded as their decomposing points, and that the passage of an inert gas through the solution is not necessary to accomplish this. He considers their dissociation in solution to be analogous to the evaporation of the solvent.

The writer then endeavored to ascertain how this loss could be prevented, and what the limit of delicacy of the test is. Evaporation of standards seemed to be the only practical way to perform this part of the work. I used a solution of potassium nitrate, only one tenth the strength of that employed by Grandval and Lajoux, and evaporated portions of 0.05 c.c. to 1.00 c.c. only. The evaporation of this small amount required but very few minutes, and the loss must have been very slight, or at least constant for each amount used, as the colors could in this way be matched exactly.

It was my first endeavor to try to detect the amount of nitrate lost by distilling the solutions, and testing each successive 10 c.c. of the distillate. Of course a loss occurs during the evaporation, but if even a faint color could be obtained it would prove that some of the nitrate was carried over during distillation.

The first experiment consisted in distilling 200 c.c. of a solution which contained 0.1 grm. $N_2 O_5$. The first 10 c.c. that came over gave a slight

yellow color. The next 17 portions, each of 10 c.c., gave only a very slight color, which could hardly be called a yellow, yet it was darker than the color obtained by simply evaporating 10 c.c. of distilled water; when a comparative experiment was tried of distilling 200 c.c. of distilled water the successive portions of 10 c.c. of the distillate gave, on evaporation to dryness, a more pronounced tint than in the last mentioned experiment, but it was not so decided as when the nitrate solution was used. There is a possibility of there being a minute trace of nitrates in this distilled water, but these colors are far below anything that can be estimated. Portions 19 and 20 both gave a decided yellow. The amount in these two portions was .0002 grm. $N_2 O_5$. As the last portion came over just preceding dryness, possibly some of the nitrate may have been carried over by spattering or over-heating. A second experiment with only 100 c.c. of a solution which contained .005 grm. $N_2 O_5$ was tried in the same way. In this, the first eight portions gave the same very faint brownish color, which had to be compared with the color produced by treating distilled water in the same manner in order to be appreciated. The ninth portion was a very faint yellow, the tenth contained .00003 grm.,—a much larger amount in proportion to the total present than was obtained in the first experiment.

Upon adding 50 c.c. of distilled water to the dry residue, as left in the flask after concentration of the 100 c.c., and again distilling, the first portion distilled was found to contain .0000035 grm. This, however, was proved to be due to a few drops left in the condenser from the previous distillation. The last portion contained .0004 grm., and the one before it .000002 grm. The addition of several successive portions of pure water of 50 c.c. each, gave, when distilled, approximately the same results. Two repetitions of this experiment from its starting-point proved the figures to be practically correct.

The presence of nitrates in the distillate is the result of one or more of four causes: volatilization, mechanical transportation by the steam, superheating, or spattering. To eliminate the last of these, a three-bulbed tower was inserted at the neck of the flask. By experiment it was found that this made no difference in the results. To prevent super-heating as far as possible, the flask was heated in a calcium chloride bath. A thermometer was also inserted in the tower, its bulb being just below the side orifice through which the steam escaped to the condenser. The temperature of the bath varied from 120° C. to 135° C., and by the use of this bath the last 10 c.c. distilled were not over-heated, as they undoubtedly were in the previous experiments. The mercury in the thermometer at the top of the tower stood at 98° C., until the last portion of the water had evapo-

rated, when it slowly fell, notwithstanding the fact that the bath was kept hot in every experiment fully 15 minutes after all the solution had evaporated.

100 c.c. of a solution containing .005 grm. were distilled under these conditions, and the distillate tested as before. By this treatment more than .00001 grm. was never obtained in the last portion, the average being about .000005 grm. Evidently heat plays the important part in driving the nitrates over, but whether they are carried over mechanically, or are volatile at the temperature employed, was not determined; but from what has already been stated, the experiments would seem to favor the latter view.

A number of experiments were made to see what was the influence of the rate of evaporation. I found that solutions of all strengths, when evaporated quickly on an iron plate, yet without boiling, all gave, when tested, less color than those evaporated on a water-bath; while those evaporated by long standing at ordinary temperatures or over sulphuric acid gave about the same color as those on the bath, and in a few cases even a trifle less,—the reason for which is not apparent.

The effect of dilution and then evaporation is also to cause a loss. This was prettily shown by the following experiment: Solutions were made each containing 2 c.c. of a standard nitrate solution, 1 c.c. of which was equal to .00005 grm. $N_2 O_5$. The first was not diluted, to the second was added 5 c.c. of distilled water, to the third 10 c.c., to the fourth 25 c.c., and to the fifth 50 c.c. After evaporation, numbers one and two gave about the same color; while the colors of the others diminished, in regular order as the amount of water which had been added increased.

These experiments indicate that the best method of evaporation is by means of the water-bath, and as small a quantity as possible to give a color should be used. I find it best to work with less than 10 c.c., provided that amount will give a color requiring about 0.5 c.c. of my standard solution to match it. The colors produced by this and approximate quantities are the easiest and most accurate to read, provided 10 c.c. Nessler tubes are employed. In cases where 10 c.c. do not give a color, the solution may be concentrated in such a flask as that previously described, thereby avoiding much loss.

To test the delicacy of the method, I used solutions whose strengths were unknown to me until after the completion of the work. In cases where the solutions were very dilute, large amounts were concentrated in the flask to about 10 c.c. The flask was then emptied, rinsed with a few drops of distilled water, and this added to the dish containing the above amount, and then the whole evaporated. Portions of the distillate tested during concentration gave no color. The table here inserted gives my results.

No. of the solution.	No. c.c. evaporated in porcelain dish.	No. c.c. concentrated in flask.	Parts N_2O_5 in 100,000 found.	Parts N_2O_5 in 100,000, theoretical.
1	10	. .	1.50	1.50
1	2	. .	1.425	1.50
2	10	. .	1.40	1.25
2	5	. .	1.15	1.25
2	2	. .	1.35	1.25
3	10	. .	0.86	1.00
3	5	. .	0.85	1.00
3	2	. .	1.05	1.00
3	2	. .	1.05	1.00
4	1	. .	0.35	0.50
4	5	. .	0.44	0.50
5	10	. .	0.250	0.375
5	10	. .	0.215	0.375
6	5	. .	0.230	0.300
6	10	. .	0.230	0.300
7	10	. .	0.250	0.250
7	10	. .	0.225	0.250
8	10	. .	0.095	0.125
8	10	. .	0.090	0.125
9	10	. .	0.065	0.100
9	10	25	0.076	0.100
10	10	. .	0.030	0.060
10	10	100	0.045	0.060
10	10	50	0.043	0.060
11	10	50	0.034	0.050
12	10	. .	No color.	0.030
12	10	50	0.018	0.030
12	10	100	0.0175	0.030
12	10	100	0.0170	0.030
13	10	. .	No color.	0.015
13	10	100	0.0075	0.015
13	10	300	0.0105	0.015
13	10	300	0.0087	0.015

Two things are to be noticed in connection with this table: first, in almost every case the results came below the theoretical,— in other words, there is a loss which does not occur on the evaporation of the small amounts of the standard; and, second, that the weaker the solution the greater the proportional, but the less the actual loss.

From the above results the following conclusions are drawn: — the method is not absolutely accurate in very weak solutions, but the presence of one part in 100 millions can be detected. About one part in one million can be closely determined without any concentration, which is always to be avoided when possible, since it changes the shade of color on account of the proportional increase of organic matter. Most of this can be filtered off before pouring the liquid into the Nessler tube; but with river and pond waters which contain but slight traces of nitrates and nitrites and much organic matter, it will be necessary to eliminate the latter. This may be done to a great extent by concentrating a large volume in a flask with some salt free from nitrates, as alum (chlorides can not be used), transferring to a smaller flask after filtration, and there concentrating to 10 c.c. as usual. The water can, if necessary, be filtered again before evaporation, and a comparatively clean residue will be obtained.

If a water contains a large amount of nitrates or nitrites one must dilute it, so that less than 10 c.c. will be required to match 0.5 c.c. of the standard here employed. The reasons for so doing are, that the deeper shades cannot be matched so accurately as those containing from 1.0 c.c. to .05 c.c. of the standard; and, morever, the strong sulphuric acid used will decompose some of the nitrate if a large amount be present I can recommend this method in preference to all others as being the simplest and most rapid. In delicacy and accuracy, it equals if it does not exceed other methods.

LABORATORY OF SANITARY CHEMISTRY; April, 1887.

THE CORRECTION-FACTOR OF A GALVANOMETER-COIL WHEN THE NEEDLE IS DISPLACED ALONG THE AXIS.

(AN ELEMENTARY DEMONSTRATION.)

Presented at a meeting of The Am. Acad. of Arts and Sciences, May 11, 1887.

BY J. J. SKINNER, PH.D.

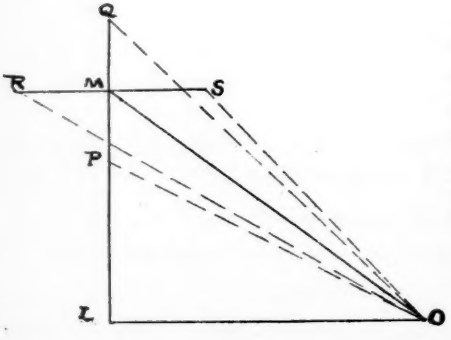
THE text-books of Lamont, Wiedemann, and others lay down methods of finding by integration the effect of an electric current in a coil of rectangular section, on a magnet-pole, at any point in the axis of the coil. These methods lead to complicated results. In Maxwell's Treatise, Art. 752, he states that the magnetic force at the center of the coil, due to a unit current, is the quantity denoted by G_1 in his Art. 700. This statement would, however, seem to be too limited, since the quantity G_1 is a function of the distance from the mean

plane of the coil to a point on the axis where the magnetic force is supposed to act. Maxwell finds the value of G_1 as one of the results of a method of approximation by the use of harmonics and the calculus. Mr. H. V. Hayes, in a paper communicated to the Am. Acad. of Arts and Sciences, Nov. 11, 1885, and Dr. R. W. Willson, in Annalen der Physik und Chemie, Neue Folge, Band XXVI., 1885, have also treated the subject by the calculus; and the latter also gave some curves showing to the eye the changes due to the coil-section, the galvanometer needle being displaced along the axis of the coil.

The object of the present paper is to give an elementary algebraic deduction of the factor of correction for the current in a coil, as determined by a short magnetic needle at any point on the axis of the coil, the section of the coil being rectangular, and not too large in comparison with the radius.

If a thin wire be coiled into a single circle of radius r, and carry an electric current C, and if a unit magnetic pole be on the perpendicular drawn to the center of the circle, the distance of the pole from that center being e, we have the well-known formula for the force exerted on the pole in the direction of the given perpendicular: —

$$F = \frac{2\pi r^2 C}{(r^2+e^2)^{\frac{3}{2}}} \quad . \quad . \quad (1)$$



In the figure let L O be the given perpendicular, the circle of the wire being perpendicular to the plane of the paper, its center being L, and the wire piercing the plane of the paper at M. The radius is then L M $= r$; and if the magnet pole be at O, we have L O $= e$.

Now if we suppose the single circular wire, or coil, as it may be termed, to be replaced by two coils in the same plane, and having the same center L, one of these having a radius L P $= r - d$, and the other a radius L Q $= r + d$, and suppose each of these new coils to carry a current equal to $\frac{C}{2}$, and denote the respective forces exerted at O along L O in this new case by F′ and F″, we get by using formula (1) for each, and adding,

$$F' + F'' = \pi C \left\{ \frac{(r-d)^2}{[(r-d)^2+e^2]^{\frac{3}{2}}} + \frac{(r+d)^2}{[(r+d)^2+e^2]^{\frac{3}{2}}} \right\}$$

By expanding $(r-d)^2$ and $(r+d)^2$ in the denominators, re-arranging and factoring we may write this without approximation in the form

$$F' + F'' = \frac{\pi C}{(r^2+e^2)^{\frac{3}{2}}} \left\{ \frac{(r-d)^2}{\left(1 + \frac{d^2 - 2rd}{r^2+e^2}\right)^{\frac{3}{2}}} + \frac{(r+d)^2}{\left(1 + \frac{d^2+2rd}{r^2+e^2}\right)^{\frac{3}{2}}} \right\}$$

Assuming that d is small compared with r, the expression $d^2 \pm 2rd$ will be small compared with $r^2 + e^2$. If we then develop to three terms each by the binomial formula all the binomials in the large brace in this value of $F' + F''$, then reduce the quantity in the brace to a common denominator, dropping in the result terms such as d^2, where they are added to r^2, or as d^4 when added to $4r^2 d^2$, and the like, and take out a factor $2r^2$, we get

$$F' + F'' = \frac{2\pi r^2 C}{(r^2+e^2)^{\frac{3}{2}}} \left\{ \frac{1 + \frac{d^2}{r^2} - \frac{9d^2}{2(r^2+e^2)} + \frac{3r^2 d^2}{2(r^2+e^2)^2}}{1 + \frac{3d^2}{r^2+e^2} - \frac{6r^2 d^2}{(r^2+e^2)^2}} \right\} \quad (2)$$

Since the terms after the unit in the denominator of the large brace are now small fractions, we may transfer this denominator to the numerator, by using the familiar principle of approximations, that if x is a small fraction we may substitute $1 - x$ for $\frac{1}{1+x}$. Making that change in equation (2), multiplying out, dropping the negligible terms, simplifying and substituting the value of F from equation (1), we get

$$F' + F'' = F \left\{ 1 + d^2 \left(\frac{1}{r^2} - \frac{15e^2}{2(r^2+e^2)^2} \right) \right\} \quad . \quad . \quad . \quad (3)$$

which for convenience may be written:—

$$F' + F'' = F(1 + A d^2) \quad . \quad . \quad . \quad . \quad (4)$$

A being independent of d.

Notice, that in the two coils that I have supposed to replace the original one, the total length of wire is just twice that of the original coil; and as the current in each of the new coils is half that in the original, the value of F in equations (3) and (4) is the force that would be exerted if the wire of the two new coils, still carrying the current $\frac{C}{2}$, were formed into two complete insulated circles coinciding in the position of the original one.

Now, instead of supposing the original coil to be replaced by two, let there be $2n$ coils, of different radii, all concentric and in the same plane, and spread uniformly inward and outward from the position of the original coil, the radii of the two coils nearest the original position being respectively $r-\frac{d}{n}$ and $r+\frac{d}{n}$, the radii of the coils next to these being $r-\frac{2d}{n}$ and $r+\frac{2d}{n}$, and so on, the radii of the smallest and largest coils being respectively $r-\frac{nd}{n}$ and $r+\frac{nd}{n}$; and let each of the $2n$ coils carry a current equal to $\frac{C}{2n}$. Then if f_1 and f_2 be the forces exerted in the direction L O at O by the coils whose radii are $r-\frac{d}{n}$ and $r+\frac{d}{n}$, and if f be the force which would be exerted if the wire and current of the same two coils were brought into two complete insulated circles in the position of the original one, we get by equation (4).

$$f_1+f_2=f\left(1+A\frac{d^2}{n^2}\right)$$

Similarly, the forces exerted by the next pair of coils, whose radii are respectively $r-\frac{2d}{n}$ and $r+\frac{2d}{n}$, will give us

$$f_3+f_4=f\left\{1+A\left(\frac{2d}{n}\right)^2\right\}$$

and so on, to the smallest and largest coils, which give

$$f_{2n-1}+f_{2n}=f\left\{1+A\left(\frac{nd}{n}\right)^2\right\}$$

If we denote by F_1 the total force exerted by all the concentric coils, since there are n pairs of them, we shall have, by adding n expressions like the above,

$$F_1=f\left\{n+\frac{Ad^2}{n^2}(1+2^2+3^2\ldots+n^2)\right\} \quad \ldots \quad (5)$$

Denoting by F the force that would be exerted if the total wire of the $2n$ coils were formed into $2n$ circles coinciding in the position of the original one, each carrying its own current, we should evidently have

$$F=fn, \text{ or } f=\frac{F}{n}$$

and if n is very large, we may take

$$1+2^2+3^2\ldots+n^2=\frac{n^3}{3}$$

so that by substitution equation (5) may be written

$$F_1 = F\left(1 + \frac{A\,d^2}{3}\right) = F\left\{1 + \frac{d^2}{3}\left(\frac{1}{r^2} - \frac{15\,e^2}{2\,(r^2+e^2)^2}\right)\right\} \quad . \quad . \quad (6)$$

If, then, a current C, in a wire of a single circular turn of infinitely small section, exerts along L O the force F at a point on the axis of the circle, the same current uniformly distributed in the section of a wire flattened out, as it were, in its plane, till the section has the radial depth $2d$, with the mean radius unchanged, and d being small compared to r, will exert the force F_1 given by equation (6).

We may proceed in a similar way to find the force that would be exerted if the current, instead of being spread out radially, were distributed uniformly from the original position to a width of $2b$ along the surface of a cylinder having a radius equal to that of the original coil, and extending equally on both sides of the original position, as represented by the section R S in the figure. We begin by supposing the original coil at M to be replaced by two coils, at R and S respectively, of the same radius r, each carrying a current $\frac{C}{2}$, the distances of the planes of these coils from the magnet pole O, being respectively $e+b$ and $e-b$. In equation (1) in place of e put $e-b$, and again $e+b$; add the two resulting expressions, rearrange the partial denominators so as to take out the factor $(e^2+r^2)^{\frac{3}{2}}$, assume that b is small compared to r, expand the denominators as before, to three terms each, by the binomial formula, reduce to a common denominator, rejecting negligible terms and simplifying, the sum is found to be

$$\frac{2\pi r^2 C}{(r^2+e^2)^{\frac{3}{2}}}\left\{\frac{1 + \frac{3\,b^2}{2\,(r^2+e^2)} + \frac{3\,b^2\,e^2}{2\,(r^2+e^2)^2}}{1 + \frac{3\,b^2}{r^2+e^2} - \frac{6\,b^2\,e^2}{(r^2+e^2)^2}}\right\}$$

This may be further simplified by the same method that was used in getting equations (3) and (4) from (2). Then by writing, as before, a series of expressions for n pairs of coils, and making a summation by noticing that the passage from equation (3) to (6) merely divides by 3 the quantity after the unit in the large brace of equation (3), and denoting by F_2 the resulting value of the force, we find

$$F_2 = F\left\{1 + \frac{b^2\,(4\,e^2 - r^2)}{2\,(r^2+e^2)^2}\right\} \quad . \quad . \quad . \quad (7)$$

which gives the force at O along L O due to a current uniformly spread and flowing around the cylindrical surface whose section is R S, small

compared to r, where F is the force that the same total current would exert if flowing in the wire of infinitely small section passing through M.

If, finally, we suppose the original coil to be first flattened out till the radial depth of the section is $2d$, and then this flat ring to be expanded axially or both ways from the mean plane to a total width of $2b$, b and d being small compared to r, the current C uniformly distributed in the section $2b \times 2d$ will, as we see by putting in place of F in equation (7) the value of F_1 from equation (6), exert a force denoted say by F_s equal to

$$F_s = F \left\{ 1 + \frac{d^2}{3}\left(\frac{1}{r^2} - \frac{15e^2}{2(r^2+e^2)^2}\right)\right\}\left\{ 1 + \frac{b^2(4e^2-r^2)}{2(r^2+e^2)^2}\right\}$$

and this by a final approximation may be written

$$F_s = F \left\{ 1 + \frac{d^2}{3}\left(\frac{1}{r^2} - \frac{15e^2}{2(r^2+e^2)^2}\right) + \frac{b^2(4e^2-r^2)}{2(r^2+e^2)^2}\right\} \quad (8)$$

Allowing for the change of notation, the factor in the large brace of (8) is the same as the corresponding factor of G_1 given by Maxwell in his Art. 700.

Observe now that the quantity in the large brace of (8) is a factor by which if we multiply the *force* that would be exerted by a current in a coil of infinitely small section, and radius r, we get the *force* due to a uniformly distributed current in a coil whose section has a depth $2d$ and a breadth $2b$, both small compared to r, the total current across the section remaining unchanged, r being the mean radius and e the distance of the mean plane of the coil from the unit magnet pole.

Equation (1) applies to a coil of only a single turn; but if a coil have N turns in a section so small as to be neglected, each turn carrying the current C, the only change necessary is to multiply the right hand member of (1) by N. Doing that and changing the form of the equation, it becomes

$$C = \frac{F(r^2+e^2)^{\frac{3}{2}}}{2\pi N r^2} \quad . \quad . \quad . \quad (9)$$

Now if α be the angle of deflection from the meridian, produced in a short needle at O by the force F_s due to a coil of N turns and a section $2b \times 2d$, if H be the horizontal intensity of the earth's magnetism, and if we for a moment represent the multiplier of F in equation (8) by Q, we shall have

$$F_s = FQ = H \tan \alpha$$

$$\therefore F = \frac{H \tan \alpha}{Q}$$

Substituting this value of F in equation (9), it becomes

$$C = \frac{H \tan a \, (r^2 + e^2)^{\frac{3}{2}}}{2\pi N r^2 Q}$$

And now again, by the principle that when x is a small fraction, $1 - x$ may be written for $\frac{1}{1+x}$, after putting into this equation the value of Q we may change the expression to the form

$$C = \frac{H \tan a \, (r^2 + e^2)^{\frac{3}{2}}}{2\pi N r^2} \left\{ 1 + \frac{b^2 (r^2 - 4e^2)}{2 (r^2 + e^2)^2} + \frac{d^2}{3} \left(\frac{15 e^2}{2 (r^2 + e^2)^2} - \frac{1}{r^2} \right) \right\} \quad (10)$$

which gives the corrected *current* in the coil, of section $2b \times 2d$. The factor in the brace is what I set out to deduce.

The curves corresponding to the terms depending on b, d, and e may occasionally be useful to those who are comparing the action of coils. If we express the distance e in terms of r, that is, let $e = r x$, we may write the term of (10) that contains b in the form

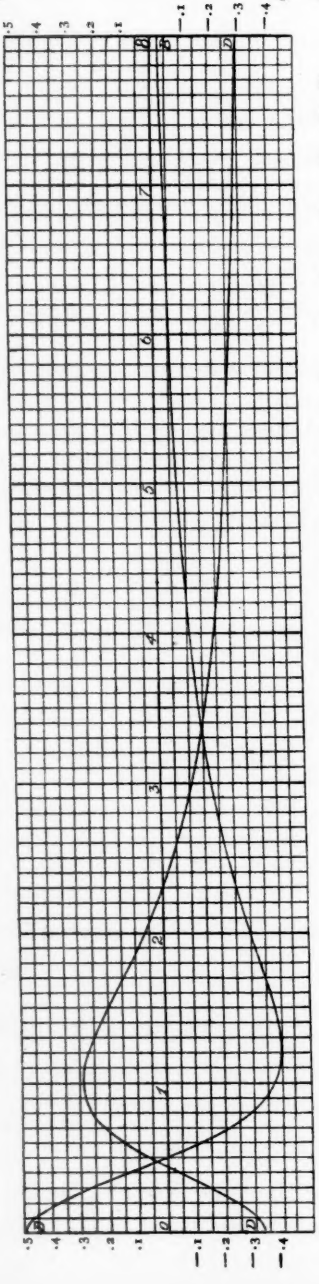
$$\frac{b^2}{r^2} \times \frac{1 - 4x^2}{2 (1 + x^2)^2}$$

and the term that contains d in the form

$$\frac{d^2}{r^2} \times \left(\frac{5 x^2}{2 (1 + x^2)^2} - \frac{1}{3} \right)$$

The curve B is constructed by taking values of $x = \frac{e}{r}$ as abscissæ and computing the corresponding values of $\frac{1 - 4x^2}{2 (1 + x^2)^2}$, which are laid off as ordinates, and similarly the curve D is drawn with ordinates equal to different values of $\frac{5 x^2}{2 (1 + x^2)^2} - \frac{1}{3}$.

To use the curves for the practical correction of current observations, with a given value of $\frac{e}{r}$ as abscissa, multiply the corresponding ordinate of the curve B by $\frac{b^2}{r^2}$ to get the term of correction depending on the breadth of the coil section; and multiply the corresponding ordinate of the curve D by $\frac{d^2}{r^2}$ to get the term of correction depending on the depth of the coil section, remembering that the breadth of the coil section $= 2b$ and the depth $= 2d$. I have only used positive values of $\frac{e}{r}$, as negative values give the same values of the ordinates.



A simple application of the calculus shows that the curve of breadth correction, B, has a maximum ordinate when $x = \frac{e}{r} = o$, the breadth correction term then being $\frac{1}{2}\frac{b^2}{r^2}$. It has an algebraic minimum when $\frac{e}{r} = \frac{\sqrt{6}}{2} = 1.225$, the correction term then being $-\frac{2\,b^2}{5\,r^2}$. The ordinate is 0 when $\frac{e}{r} = \frac{1}{2}$, and also when $\frac{e}{r} = \infty$. The curve has two points of inflection, given by $\frac{e}{r} = \frac{1}{2}\sqrt{7 \pm \sqrt{41}} =$ approximately 0.39 or 1.80. The axis of abscissæ is an asymptote.

The curve of depth correction, D, has two equal algebraic minima, corresponding to $x = 0$ and $x = \infty$, the term of depth correction then being $-\frac{1}{3}\frac{d^2}{r^2}$. It has one maximum, given by $\frac{e}{r} = 1$, the correction term then being $\frac{7}{24}\frac{d^2}{r^2}$. The ordinate is 0 when $\frac{e}{r} = \frac{1}{4}(\sqrt{30} \pm \sqrt{14}) =$ approximately 0.43 or 2.30. The curve has two points of inflection given by $\frac{e^2}{r^2} = \frac{4 \pm \sqrt{13}}{3}$, or $\frac{e}{r} =$ approximately 0.36 or 1.59. A parallel to the axis of abscissæ at a distance below it equal to $\frac{1}{3}$ is an asymptote.

The ordinates of the curves were calculated for every half tenth in the values of $\frac{e}{r}$ up to 1.3, and then for every

tenth up to 4; then for 4.2, 4.5, 5, and above that for unit differences in $\frac{e}{r}$.

It is interesting to notice that the breadth and depth corrections tend to neutralize each other for values of $\frac{e}{r}$ up to 2.3, after which the current corrections are both negative. With the value of $\frac{e}{r} = \frac{1}{2}$, taken by Gaugain and Helmholtz for their galvanometers, the total correction with ordinary proportions of coil section is extremely small.

The complexity of the curves is due to the fact that they represent the changes in the component of the magnetic action parallel to the axis of the coil; and this component is evidently dependent on the angle subtended at the magnet pole by the radius of the coil, as well as on the total force exerted by each elementary part of the circuit.

The breadth correction at very large distances is negligible, and it might at first thought seem as if the depth correction should be so too; but the investigation shows that the latter is the same for $\frac{e}{r} = \infty$ as for $\frac{e}{r} = 0$. The conclusion that large values of $\frac{e}{r}$ should give large depth corrections may be understood by referring to the figure, and considering that the force exerted at O by an elementary part of the circuit passing through M is perpendicular to M O, and hence the component of this force along O L is proportional to the sine of the angle M O L. Now, if O L is very large in comparison with L M, small changes in L M will not much change the total force exerted at O by an element of the circuit, but will materially change the sine of the angle M O L, and hence change the component of the force along O L. The conclusion also agrees with the fact that at large distances the magnetic action of a plane circuit is nearly proportional to the product of its area by the strength of the current. The total area inclosed by the two coils having their sections at P and Q, which I first supposed to replace the original coil, would be more than twice the area inclosed by that one coil; so that for large values of $\frac{e}{r}$ the magnetic effect along L O of the two coils, each carrying the current $\frac{C}{2}$, would be greater than the effect of the one original coil carrying the current C.

ROGERS LABORATORY OF PHYSICS; March, 1887.

THE BUSSEY BRIDGE.

BY A. G. ROBBINS, S.B.

THE bridge which carried the Dedham Branch of the Boston & Providence Railroad over South Street was a skew bridge, and made an angle of about twenty-one degrees with the street. It was originally designed for a double track, but only one track has ever been built. This crossed on the western side of the bridge, and thus brought about four fifths of the load upon the truss on that side.

Originally the trusses were wooden Howe trusses; but in 1869 the western truss, which carried the greater part of the load, was removed, and an iron Whipple truss put in its place. In 1876 the other wooden truss was removed, the Whipple truss carried over to the eastern side, and a Pratt truss built on the western side. Thus the two trusses were of different design and of different heights, the one carrying the greater load being a Pratt truss, 16 feet deep with four panels, each 26 feet long, making the total span from center to center of end pins 104 feet. The other was a Whipple truss, $12\frac{1}{2}$ feet deep, with 16 panels, each $6\frac{1}{2}$ feet long.

On account of the differences in height of the two trusses, the floor beams were suspended from the joints of the Pratt truss, and rested on the top chord of the Whipple truss at every fourth panel.

All that is attempted in this paper is to submit some parts of the bridge to the test of calculation, in order to learn whether the bridge would carry what it was designed to carry, and also to learn in what particulars it differed from good bridges of to-day.

Some of the dimensions taken are approximate, and will differ from the real dimensions by a small amount,—not enough, however, materially to alter the results in any case.

That part of the bridge erected in 1876,—the Pratt truss and the floor system,—was built to carry a load of 3,000 lbs. per lineal foot, together with a concentrated load of 8,000 lbs. on four locomotive drivers; and with this load the iron was not to be strained more than 10,000 lbs. per square inch in tension, and in compression more than a proportionate amount after making allowance for bending by Gordon's formula. In addition there is the weight of the bridge itself, which, in this case, amounts to approximately 1,150 lbs. per lineal foot.

In the calculation of bridges it is the custom to separate these loads, the moving load being called the live load, and the weight of the structure the dead load. The reasons for this are, that the moving load comes

on with considerable velocity, and with more or less pounding, according to the condition of the track; also, that it is not uniformly distributed, but is concentrated at points; moreover, this distribution is not constant, but varies with the kind of load, the condition of the track, the speed and motion of the train, and the force and direction of the wind. Taking these considerations into account, the live load is generally considered at least twice as destructive as the dead load.

The following table gives the stresses in each member of the Pratt truss under a live load of 2,400 lbs. per lineal foot, and a dead load of 750 lbs. per lineal foot, and also the stresses per square inch in those members whose dimensions were known. Plus indicates compression, and minus, tension.

Member.	Stresses due dead load, lbs.	Stresses due live load, lbs.	Total Stresses.	Stress per sq. in. lbs.
a b	+57200	+189700	+246900	
b c	+69900	+215800	+285700	
b h			+40000	+13300
c g	+24000	+70400	+94400	+7000
a h	—48800	—161900	—210700	—8800
c h	—7600	—10700	—18300	—9100
b g	—24890	—67100	—91900	—9300
h g	—45400	—161900	—207300	—8700
hangers at b				—48400

Fig. 1 (on following page) shows position of the members. The general position of the two trusses is shown by Fig. 2, and the hangers at *b* by Fig. 3.

The load coming from the floor-beam at *b*, is transmitted to the truss through the hangers at *b* and the post *b h*, the relative amount depending on the workmanship and the elasticity of the material. Now, if the post is loaded with its breaking-weight it would relieve the hangers of about 40,000 lbs., leaving 41,400 lbs. which must be borne by the hangers. Just above the eye the dimensions of each hanger were $1\frac{5}{8}$ by $2\frac{1}{4}$ inches, and the greatest lever-arm of the load was approximately two inches. If both hangers were equally loaded, there would be on each hanger a load of 20,700 lbs., acting under a leverage of two inches,

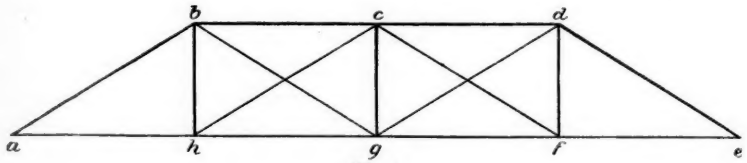


Fig. 1.

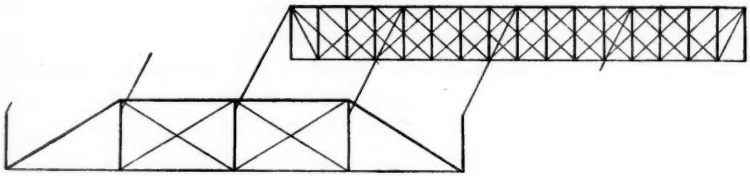


Fig. 2.

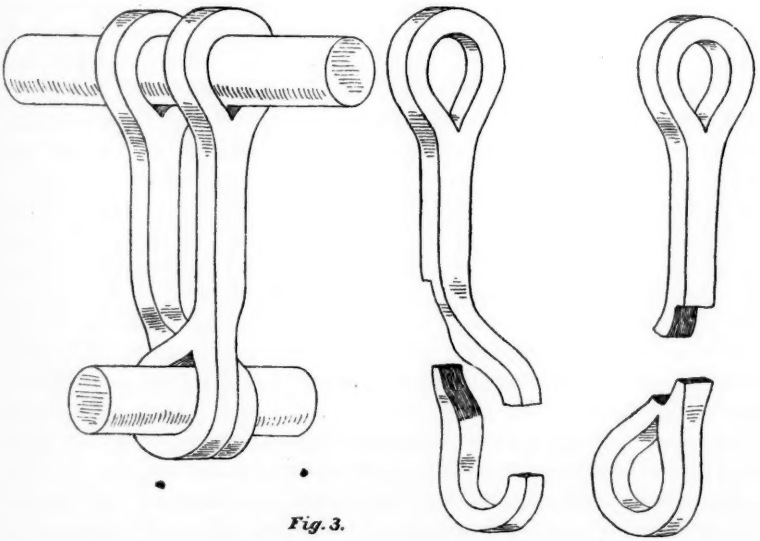


Fig. 3.

which gives a maximum fiber stress of 48,400 lbs. per square inch, or about nine tenths of the breaking-weight of good wrought-iron. Thus, instead of being subject to a load of 10,000 lbs. per square inch, the post and hangers at *b* were loaded so heavily, that a comparatively few applications would certainly break them, even if the workmanship and

material were of the best,—a supposition which the condition of the hangers at the time of the accident would hardly warrant.

To make the matter worse, these hangers were so concealed that they could not have been properly inspected since the bridge was built. This gives a forcible illustration of the necessity of adhering to that only safe rule in bridge inspection, "that all parts should be considered unsafe until they can be shown to be safe."

There were other, though perhaps less striking examples of defective design in this bridge, especially at the center post, *c g*. This post rested upon a casting at *g;* on its upper end was another casting; and between this last and a third casting in the upper chord at *c*, rested one end of the floor-beam at that joint. Thus there were in this post five different pieces, placed one above the other, and held together by short lugs, which projected from some of the castings. Add to this the fact that the ties of the flooring were spaced two feet apart on centers, and there are present all of the conditions necessary for the complete destruction of the bridge in case of a derailment. For if the wheels of a crossing train should leave the rails, they would soon force their way between the ties, and thus be in a position to knock the floor-beam from its insecure support, or the upper chord out of line; either of which results would be speedily followed by the fall of the entire structure.

The manner of loading the Whipple truss at every fourth panel only, left one entire system unloaded, and was without precedent in the history of good bridge-building.

The lower chord-splice in the Whipple truss was about as defective as it could be. Two bars six inches by seven eighths of an inch were connected by splice-plates, fastened at each end with a bolt one and three-eighths inches in diameter; a connection which is less than half as strong as the bars which it joins, but which could and should have been made of at least equal strength.

In closing, it is well to notice that this bridge was built without any real specifications, inasmuch as nothing was said about the method of calculation, no allowance being made for the greater destructiveness of the live load; nor was anything said about the arrangement of details. It is also well to notice that the actual wheel-loads were not taken into consideration in designing the floor system, although such loads would cause considerably greater stresses than the loads taken. The latter were, however, sufficient to destroy the bridge, and no greater load could do more.

Mass. Inst. Technology; April, 1887.

PERSISTENT MÜLLERIAN DUCTS IN MALE PICKEREL FROGS.

BY W. T. SEDGWICK, PH.D.

THE frogs most often for sale in the Boston markets during the winter are middle-sized specimens of the green pickerel frog, *Rana halecina* of Kalm. As early as the winter of 1883, it was observed by the workers in the biological laboratory that the males of this species exhibit a peculiarity in the shape of a conspicuous pair of highly developed Müllerian ducts, lying in the usual position of the oviducts in the female, upon the dorsal wall of the body cavity. Careful observations, often repeated by different students since that time, have abundantly confirmed the earlier discovery, so that it may now be considered as settled, that the adult males of the pickerel frogs sold in Quincy market during the winter, ordinarily possess conspicuous and peculiar Müllerian ducts.

Anatomy. To expose these organs it is only necessary to kill the animal, lay it upon its back, slit up the ventral integument and body wall along the median line, draw aside the flaps, and remove the allantoic bladder. Two pale and irregularly twisted cords will then be seen, one on either side of the cloaca, to which each is attached behind, and from which it passes obliquely forward, parallel to the ureter. Each duct is at first several times larger than the ureter, and, unlike the latter, is much twisted in a zigzag fashion; but as it passes forward it gradually narrows in diameter, especially near the anterior border of the Wolffian body, or "kidney," from which region it continues obliquely forward and outward in the dorsal peritoneum, soon becoming thread-like in size, and finally disappearing at the roots of the lung. It thus appears that these organs agree exactly in position with the ordinary oviducts of female frogs.

Histology. An extensive series of sections for the microscopic study of the ducts has been made by Mr. S. R. Bartlett. For this purpose they were fixed by corrosive sublimate or similar hardening fluids, stained with borax carmine, soaked in soft (the so-called "chewing-gum") paraffin, and cut in "ribbons" by the microtome, the usual method in such cases. The sections show a lumen almost always present, and surrounded in the lower portion by a richly glandular epithelium, which is often folded longitudinally. Cilia occur, at least in the lower portions, and the glands, etc., correspond closely with the similar and characteristic structures of true oviducts in female frogs.

Homology. There can be no question whatever as to the homology or morphological significance of these organs. They are rudimentary oviducts, or, as it is perhaps better to call them, peculiar and highly developed Müllerian ducts. It is well known that in the higher vertebrates the sexes begin, and for a time develop, in exactly the same way, so that sex is a clearly secondary characteristic, males and females beginning to differ from one another only at a comparatively late period of embryonic life. In both there arises very early in development a pair of organs known as the Müllerian ducts. If the animal becomes a female, these are turned to account, either as simple passages for the eggs from the ovary to the exterior, or, as in the hen, become organs for the laying on of albumen (the white-of-egg) and of the shell; or, again, as in the frog, for the laying on of a special kind of white-of-egg, — the familiar jelly in which frogs' eggs are imbedded when laid,— which serves for shelter and food for the young tadpoles very much as the white-of-egg does for the young chick. If the embryo becomes a male, however, the Müllerian ducts are usually aborted, though rudiments not infrequently remain even in the highest animals. For example, Professor Leuckart* many years ago worked out and described, in man and other mammals, numerous cases in which rudiments of these organs are found.

Similar cases occur in birds and reptiles (examples having been observed in turtles in our own laboratory), while in toads and tailed amphibia they are very common. Frogs, however, are generally destitute of conspicuous rudiments of this kind; and a somewhat careful study of our commoner species has failed to show anything for a moment comparable to the very constant and highly developed Müllerian ducts of the pickerel frog. The bull-frog, *R. Catesbiana*, and the leopard frog, *R. palustris*, certainly show nothing of the kind; while Weidersheim, in Ecker's† somewhat detailed work, mentions the subject only in a foot-note, and does not appear himself ever to have seen male Müllerian ducts in frogs. We owe to Spengel‡ the best account we have of the urinogenital apparatus in amphibia; but Spengel does not appear to have observed the presence of these ducts in *Rana halecina*. It should be added, however, that he had only alcoholic specimens of this species to work with, and that he confirms the discoveries of others who describe slender Müllerian tubes in *R. temporaria*, etc.

* *Todd's* Cyclopædia of Anatomy and Physiology, Vol. IV., pp. 1415–1429.

† Anatomie des Frosches, III., 49.

‡ *Spengel*, Das Urinogenitalsystem der Amphibien. *Arbeiten aus dem Zoöl. Zoöt. Inst. in Würzburg, Bd. III.*, 1.

Aside from their morphological importance these tubes seem likely to prove of physiological interest. Recent observations in the biological laboratory tend to show that in *R. halecina*, in the breeding season, these ducts serve as *vesicula seminales;* and also that they may act in summer as storage-cavities for water, to prevent the desiccation of the animal during its wanderings from pools or water-courses. This species of frog is certainly found farthest of any from such sources of water supply, and it is quite possible that these tubes in the male and the oviducts in the female may be the reason for the fact.

For teachers, the existence of these organs is fortunate, since they permit a simple and striking demonstration, in a familiar and easily obtainable animal, of a conspicuous example of those "rudimentary" organs which figure so effectively in the modern theory of descent.*

MASS. INST. TECHNOLOGY, April, 1887.

BUILDING LAWS AND THEIR ENFORCEMENT.

BY T. M. CLARK, A.B.

PERHAPS no branch of jurisprudence dates back to a more remote antiquity, or presents greater variety of detail, than that which concerns itself with laws relating to building; and a thorough exposition of the subject would form an historical essay of no small interest. In one way or another building laws have existed ever since men began to live in towns, even though those towns consisted of structures which would seem to us very simple. Perhaps the Athens of antiquity presented the humblest appearance of any city which has had much influence in the affairs of the world. Although its temples were of marble, its houses were, during its greatest period, barely more than huts; and the nearest approach, perhaps, to a building law dating from that time, consists in the regulation that those persons who had their front doors, to save space, open outward over the sidewalk, as do those of many Boston houses at this day, should pay a tax to the municipality for the use of the public thoroughfare, and should, when they came out of their houses, knock loudly on the inside of the door before opening it, in order that persons passing by on the sidewalk

* See *Darwin*, Origin of Species, Am. Ed., p. 404–409; Descent of Man, p. 23. *Spencer*, Principles of Biology, I., 384. *Romanes;* The Scientific Evidences of Organic Evolution, p. 39.

might be warned in time to avoid collision with the opening door. Although no example of an ancient Grecian house now exists, even in ruins, and we have nothing to indicate what it was like except the description in Vitruvius, and occasional references in the ancient writers, it is probable that, at least in the large cities, they were built in blocks, perhaps with party walls between them; and the absence of special regulations on the subject of building tends strongly to show that they were usually only one story in height.

The Romans, who, in matters of architecture, are commonly classed with the Greeks, really differed from them in almost every detail of this, as of every other subject. While the Greek was happy in his gossipy out-door life, and so long as he could make a fine appearance at the public festivals, troubled himself little about his habitation or his property rights, the austere Roman watched his neighbors with a vigilance which was by no means uncalled for, and was generally quite ready to punish any carelessness on the part of others by appropriating some of their property to his own use. So far as we can understand the object of the Roman rules, it seems to have been mainly with a view of emphasizing the inviolability of private rights that no person was allowed to build to the boundary of his land. In Rome, even more than in the England of to-day, every man's house was his castle; and, crowded as the population was within the city walls, so sacred was this principle held to be, that it was regarded as an infringement of it for an owner merely to touch with his wall the wall of an adjoining building; and repeated statutes fix at two and one-half feet the smallest distance which must intervene between two buildings on adjacent properties.

A town so built could not accommodate in one-story houses anything like the Roman population; and the keen, money-loving landlords, restricted in the horizontal dimensions of their buildings, consoled themselves by carrying the vertical dimensions to the utmost limit that the public authority would permit. The great mass of the people of the city, as in New York at the present day, lived in tenement-houses, and these tenements were in Rome very commonly seven or eight stories high,—and would have been built higher still if the cupidity of their owners had not been checked by many edicts limiting the height of such structures. The Roman buildings, with their plastered floors, their partitions made with reeds instead of laths, and their liberal use of brick, were much less inflammable than ours, and the two and one-half foot space by which every one was surrounded checked very effectually the spread of fire; but Nero found means to overcome these obstacles to his amusement, and after the realistic presentation of the

Siege of Troy with which he gratified his courtiers one night, a considerable part of the city had to be rebuilt, and at this time laws were enacted to compel the use of incombustible materials in the exterior walls.

With the fall of the Roman Empire the reign of edicts and prefects came to an end, and every person, as well as every community, began to follow his own ideas of right and wrong in this as in other matters. That collision of differing ideas which leads to the adoption of a code of compromises began, however, to occur in a great many localities, as soon as the world recovered its breath a little after the irruption of the barbarians. So long as the plains of Europe were ravaged by Huns from the east, Norsemen and Danes from the north, and Moors and African pirates from the south, to say nothing of the barons and their retainers from the neighboring castles, the first condition of safety for peaceable persons was to find a habitation inside a walled and fortified inclosure; and as building and defending a long line of fortified walls is an expensive matter, the poor mechanics and runaway slaves who collected in the towns contented themselves with dwellings crowded, in ways which we can hardly conceive, into the smallest space which could be made to contain them all. Under such circumstances the civic spirit which comes from the mutual reaction upon each other of minds brought for a long time in close contact became very highly developed; and the rights and privileges of citizens were of necessity strictly and clearly defined. All this was done, however, in a perfectly democratic spirit. Very few mediæval cities would brook interference with their municipal affairs by outside authority, and the rules and customs which came to have the force of law in each place were adopted, one after another, by common consent of the citizens; and, naturally enough, the code for each town differed from that of every other. The question of party-walls was everywhere the one most prominent. Where every inch of space and every unnecessary pound of material must be saved, the advantage of having every side-wall serve for two houses instead of one was obvious; but the interest of the joint owners in such walls was not always easy to define, and the codes of customs usually devoted much space to the subject. For a long time these codes were entirely unwritten, the law in regard to building being determined in court, as customs of trade are now, by the evidence of persons familiar, from their professional experience, with matters relating to the subject; but in the fifteenth century Charles VII., King of France, which was then the most civilized state in Europe, appointed commissioners to go from town to town and province to province and collect, from persons of

experience, a description of the local customs prevailing in each, which should be digested and recorded for the use of the royal judges and the Court of Parliament. In this compilation the Custom of Paris, as the chief city of the kingdom, was most important, and that of many smaller places was afterward assimilated to it; but the rival towns held with tenacity to their own code, and although the Custom of Paris, which has been republished and commented upon a score of times, forms the foundation of the common law of France in building-matters, in certain places the local custom, dating back five or six hundred years, still takes precedence of it. The latest of the editions, perhaps, which was published just before the greater part of the French common law, founded upon mediæval usages and customs, was superseded by the more definite provisions of the Code Napoléon, presented the unusual form, for a law-book, of a poetical composition. The poetry was not of the first order, but the work at least presented the substance of the long series of detached propositions of the official text in a skillfully abridged form; and one paragraph, which shows the sensible view which the law then took of the question of using a neighbor's wall, built wholly on his own land, as a party wall, is worth quoting. According to this rule: —

Si contre le mur du voisin
Qui ne sera pas mitoyen
On veut faire quelque bâtisse,
Rien n'empêche qu'on ne le puisse
Pourvu qu'on paye auparavant
Moitié de la valeur réelle
Du mur et de son fondement,
Jusqu'à la hauteur seulement,
De la construction nouvelle,
Et ce, paravent que bâtir
De même que rien démolir;
Et pour l'estimation faire,
On doit comprendre dans le prix
La terre où le mur est assis,
Au cas que le propriétaire
Tout entier sur son fonds l'ait pris.

As in other matters, so in those relating to building, the mutual rights of citizens, rather than those existing between the community and the citizen, formed, before the French Revolution, the subject of legal interference. The tradition of individual liberty, which Christianity had, perhaps, been the means of introducing into the ancient world, where previously the State was everything and the citizen nothing, had persisted in theory down to that time; and the only way in which the pub-

lic authority interfered with the citizen's liberty of building as he liked was in the way of enforcing local customs, and deciding disputes between neighbors as quickly and efficiently as possible. To this end sworn experts were appointed, whose office it was to visit both new buildings, and those showing signs of weakness through age, and to pronounce upon the repairs or alterations needed to bring them into conformity with the practice of sound construction. These experts reported to the "parloir aux bourgeois" of their town, which finally decided the disputes in reference to which the advice of the experts was sought; and it appears that their opinion was regarded as of great value, as architects of the highest reputation were frequently found among them, and it was not only forbidden, under a very heavy fine, to any person not holding this appointment to presume to act as expert in technical matters, but no judge could nominate, or private person agree by contract to employ, any person not so appointed to examine or pronounce upon any technical subject.

With the Republic and the Empire came a return to the classical views of a citizen's duties. The prefect took the place of the "parloir aux bourgeois" in regulating building matters, and he administered, not the local custom, but the Code Napoléon, to which was afterward added, little by little, a considerable body of police regulations, prescribing first the width of streets, then the height of structures abutting on them, then the area of courtyards, and so on; until building in French cities, and particularly Paris, is in some respects more hampered by law than in any other civilized community, although in a different way.

In England, so far as we know, nearly the same idea of individual license in respect of building prevailed as elsewhere until the great fire of 1666, when more than thirteen thousand houses, covering four hundred and thirty-six acres of ground, were destroyed. Under the reign of Queen Elizabeth certain acts were passed for the regulation of construction in London, one of which was that only one family should dwell in a house; but no more of the kind are recorded for nearly ninety years, when, after the great fire, several acts were passed, and these have been repeatedly amended until they have been brought into the present form of the Metropolitan Building Act, which has served as the model for all those adopted in our own country. There is, however, an important difference in regard to the method of enforcement between the London law and that of New York or Boston. In the American cities the whole matter of the execution of the statute is committed to a corps of salaried inspectors, the chief of whom examines plans submitted to him, criticises, rejects or approves them, and details a

deputy to inspect, from time to time, the work carried out from them, to see whether it is done in conformity with them, and in accordance with the provisions of the statute in regard to materials and details of workmanship. The chief inspector is usually an architect, or well-qualified expert, and the deputies are experienced mechanics; and any contravention of the law is reported by the inspectors, and punished by fine or imprisonment. In London, instead of a centralized bureau, the law is administered by district surveyors, who are always architects, and often men of very high standing in the profession. Each of these has a certain territory under his jurisdiction, and plans for all buildings to be erected within that territory must be approved by him. Instead of a salary from the public treasury, the district surveyor is paid by fees, established by law, and paid by the person intending to build; and in some parts of the city, where building operations are active, these fees amount to a large annual sum, and the surveyor's time is fully occupied in his official duties; while in other districts, where fees come in slowly, the incumbent has leisure to practice his profession as architect, which he is always allowed to do. In addition to the approval of plans, the district surveyor, either in person or by deputy, is charged with the examination of buildings in process of erection, and the ordering of changes which he thinks necessary; and if his orders are disobeyed he has only to complain to the magistrate of the district, who sees to the punishment of the offender.

MASS. INST. TECHNOLOGY; April, 1887.

THE CONSTITUTION OF BENZOL.

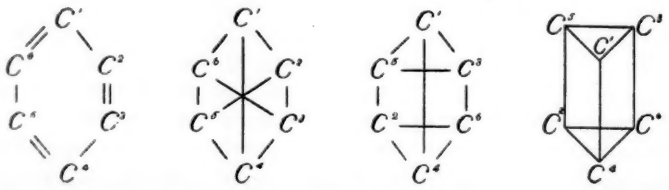
BY A. A. NOYES, S.B.

THERE is probably no single chemical question which has been the object of so much discussion and of so many hypotheses, as that of the constitution of benzol. As this is still the subject of a most active controversy, I have thought that it would not be without interest to bring together the most important facts, found scattered through the chemical literature of the last twenty years, having a bearing on the structure of benzol, and to review some of the symbols which have been proposed to represent it. However, as the existence of six C H groups in benzol is at present a well-established fact, I shall confine myself to a presentation of those experiments which throw light on the method of bonding between the carbon atoms, referring

those who may be interested in the proof of the equivalence of the hydrogen atoms, to Ladenburg's "Theorie der aromatischen Verbindungen."

Of the various symbols which have been proposed to represent the constitution of benzol, the three shown in the diagrams below have received most attention from chemists: —

I. II. III.



The first is that originally proposed by Kekulé, in the year 1865.* It requires alternate single and double bonds between the ortho atoms. The second was proposed by Claus,† two years later, and is known as the Claus or diagonal symbol. It is characterized by nine single bonds uniting the ortho and para atoms. The third, also, was first suggested by Claus, but considered by him to be inferior to the diagonal symbol. Ladenburg,‡ however, giving to it the prism form, brought it into prominence, and it has since been known under his name. It requires nine single bonds between the *meta* and *para* atoms. That the atoms forming the bases of the prism are meta to each other, and not ortho, is proved by the fact that mesitylene, $C_6H_3(CH_3)_3$, which is known to belong to the meta series of compounds, has been shown by Ladenburg§ himself to be symmetrical: in other words, the three unreplaced hydrogen atoms stand in the same relation to the rest of the molecule. A glance at the symbol suffices to show that the only positions which three symmetrical atoms can have, are those represented by the bases of the prism (1, 3, 5 and 2, 4, 6).

This brief statement of the requirements of the different symbols will be enough to make evident the bearing of the facts about to be presented, on each of them. The experiments from which any deduction can be drawn in regard to the structure of the aromatic nucleus are not numerous, and are to some extent of a conflicting character. I shall first mention those of a purely chemical nature, and then those resting on a comparison of certain physical properties of aromatic substances with those of bodies of the fat series of known constitution.

*Ann der Chem. 137, 129. †Theor. Betrachtungen, etc., by Claus, page 207.
‡Ber. d. deutschen chem. Gesell. 2, 140. §Theor. der arom. Verb.

Before presenting the facts of a chemical nature, since some chemists seem unwilling to attach any importance to them, on account of the possibility of a molecular rearrangement, a few words may be permitted on this subject. As it is undeniably true that a rearrangement of the atoms does take place in a large number of chemical changes, this fact should make chemists careful not to attach too great a significance to a single reaction. But if a number of chemical reactions are known leading to a certain symbol for any substance, this appears to offer the strongest argument for that symbol. For is it not for the very purpose of representing these chemical relations that structural symbols are used? And there can certainly be no higher criterion of the correctness of a symbol than its fitness for the purpose for which it is intended.

FACTS OF A PURELY CHEMICAL NATURE.

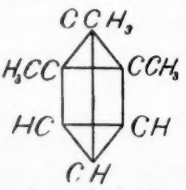
1. *Formation of benzol from ethylene.* — Berthelot, on submitting acetylene* and ethylene† to a high temperature, found that the products of the action consisted of benzol, styrol, naphthalene, and some other hydrocarbons. The experiment was repeated with ethylene last year in the chemical laboratory of the Institute. In addition to the products noticed by Berthelot, the butine, vinylethylene, $CH_2 = CH - CH = CH_2$, was identified, and no acetylene could be detected. The identification of this butine appears to me of importance; for it is without much doubt the intermediate step in the formation of benzol; and as it is known to contain two double bonds, as indicated in its formula, it is improbable that these undergo any change in the condensation of another molecule of ethylene to form benzol. The only reasonable explanation that can be given of the formation of this series of compounds (C_4H_6, C_6H_6, C_8H_8, $C_{10}H_8$), is to suppose them formed by the successive condensation of ethylene molecules, as is indicated by the following equations: —

$$2\,CH_2 = CH_2 = CH_2 = CH - CH = CH_2 + H_2$$
$$CH_2 = CH - CH = CH_2 + CH_2 = CH_2 = C_6H_6 + 2\,H_2$$
$$C_6H_6 + CH_2 = CH_2 = C_6H_5 - CH = CH_2 + H_2$$
$$C_6H_5 - CH = CH_2 + CH_2 = CH_2 = C_{10}H_8 + 2\,H_2$$

It must be admitted, however, that the high temperature required for the accomplishment of these reactions makes it not very improbable that a molecular rearrangement may take place. Nevertheless, this synthesis of benzol is *one* fact which finds its best representation in the Kekulé symbol.

*Ann. chim. phys. (4) 9, 469. †Comptes Rendus 66, 624.

2. *Formation of Mesitylene from Acetone.*—It has been known for a long time that by the action of sulphuric acid on acetone, mesitylene is formed. In order to explain this, it is necessary to assume that three molecules of water are withdrawn from three of acetone in such a way that the oxygen and hydrogen are drawn from different molecules of acetone. By far the simplest and most probable explanation is, that the two hydrogen atoms necessary to form each molecule of water are withdrawn from the same carbon atom, thus giving rise to three double bonds. This is not absolutely necessary. The two hydrogen atoms can be drawn from two different carbon atoms, causing six single bonds between these atoms and those to which in acetone the oxygen is attached. The reaction in question, therefore, is explained most probably by Kekulé's symbol, but may also be explained by that of Claus. It cannot, however, be explained by the prism symbol; for the latter, as stated above, requires that the three $C-CH_3$ groups be bonded with each other, and it is evidently impossible to withdraw water from acetone in any way that will satisfy this condition.



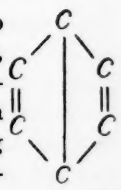
3. *Formation of Hydrochinon from Dibromacetacetic Ether.*—Wedel* and Geuther†, by a study of acetacetic ether, come to the conclusion that it has the constitution $CH_3-COH=CH-COOC_2H_5$, both on account of its resemblance to phenol in forming a violet coloration with ferric chloride, and in forming salts with alkalies, and on account of its conversion to chinonhydrodicarbonic ether, in which Wedel has shown that a hydroxyl group is present. Its conversion to chlorcrotonic acid by phosphorus pentachloride, instead of to dichlorbutyric acid, as the formula usually adopted would require, furnishes additional evidence of the correctness of Geuther's symbol.

Now, Wedel has shown that when dibromacetacetic ether is treated with sodium, the ether of chinonhydrodicarbonic acid, $C_6H_2(OH)_2(CO_2C_2H_5)_2$, is formed, the acid of which gives, on distillation, hydrochinon (paradioxybenzol). It is, therefore, probable that in this substance, as in the acetacetic ether from which it is formed, double bonds are present. A satisfactory explanation, however, of the union of the two, $=CH-COH=CCO_2C_2H_5-$, radicals in such a way as to give rise to *three* double bonds in hydrochinon, cannot be given; for Baeyer‡ has shown that chinonhydrodicarbonic acid is paradioxyterephthalic

*Ann. der Chem. 219, 71. †Ann. der Chem. 219, 119.

‡Ber. d. deut. chem. Ges. 19, 428.

acid; in other words, that the carboxyl groups are para to each other. But the symbol originally proposed by Dewar, which contains two double bonds, gives an excellent representation of this synthesis, accounting as it does for the para position both of the hydroxyl and carboxyl groups, and giving a reasonable explanation of the method in which the hydrobromic acid and bromine are withdrawn from the dibromacetacetic ether.

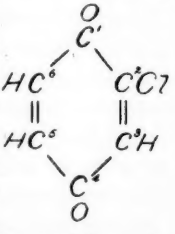


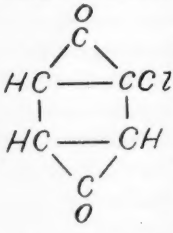
4. *Conversion of Pyrocatechin to Dioxytartaric Acid.*— In 1879, Gruber,* in acting on protocatechinic acid with nitrous acid, observed the formation of an acid, the sodium salt of which was easily broken up into sodium tartronate, C O O Na—C H O H—C O O Na, and carbonic acid. In accordance with this decomposition and the analytical figures, Gruber assigned to this acid the formula $C(COOH)_3OH$, and called it, accordingly, carboxytartronic acid. Barth,† in the next year, obtained the same body by treatment of pyrocatechin with nitrous acid. He adopted the symbol of Gruber, and called attention to the fact that since in carboxytartronic acid three carbon atoms were directly united to a fourth, it is more than probable that the same arrangement exists in pyrocatechin, from which the acid was formed, and, consequently, in the benzol nucleus. "In a word," he says, "the ring, or hexagon formula must be given up, and the prism formula adopted."

Recently, however, Kekulé,‡ by a study of the so-called carboxytartronic acid, has shown that it possesses a constitution entirely different from that supposed by Barth. By the reduction with zinc and hydrochloric acid of the sodium carboxytartronate formed from pyrocatechin, he obtained a mixture of racemic and inactive tartaric acids. Furthermore, he succeeded in preparing from tartaric acid by oxidation, sodium carboxytartronate, identical in every respect with that obtained from pyrocatechin. These facts indicate clearly a constitution for the carboxytartronic acid closely analogous to that of tartaric acid. The analytical results, moreover, show that it is tetroxysuccinic acid, $COOH-C(OH)_2-C(OH)_2-COOH$. As this acid does not contain any carbon atom attached to three others, Barth's argument against Kekulé's symbol is without foundation; and while we are not justified in drawing an absolute conclusion against the prism formula, yet it may at least be granted that the formation of the acid from pyrocatechin can be explained in a much simpler manner with the aid of the hexagon than of the prism formula. With the latter, it is necessary to suppose five single bonds broken.

* Ber. d. deut. chem. Ges. 12, 514. † Monatshefte 1, 869. ‡ Ann. der Chem. 221, 230.

5. *Conversion of Benzol to Trichloracetacrylic Acid.*— Carius,* by the action of chlorate of potassium and sulphuric acid on benzol, obtained an acid to which he gave the name trichlorphenomalic acid. Kekulé and Strecker† were the first to point out its true constitution and its important bearing on the structure of benzol. They showed from the analytical figures, its decomposition into maleic acid and chloroform, and its forming an addition product with bromine, that it had the constitution $C\,Cl_3—C\,O—C\,H=C\,H—C\,O\,O\,H$ (trichloracetacrylic acid). They showed also that the same acid is formed from chinon, by the same treatment; and it is probable that chinon is the intermediate product in its formation from benzol. By the action of chlorine, chlorchinon is formed, which decomposes into the trichloracetacrylic acid. This is readily explained by the following formula, which, for other reasons, the authors consider the most probable symbol for chlorchinon. It will be seen that the same radical, $=C\,Cl—C\,O—C\,H=C\,H—C\,O—$, exists both in this and in the trichloracetacrylic acid. In order to explain the formation of the latter, it is then only necessary to suppose the bond broken between atoms 2 and 3, where the union is weakest, and the group C^3H oxidized to $C\,O_2$, when there is left the radical $=C\,Cl—C\,O—C\,H=C\,H—C\,O—$, which takes up two atoms of chlorine and a hydroxyl group to form the trichloracetacrylic acid. If, now, the attempt is made to explain its formation by the prism or diagonal formula,





it is necessary to assume *four* single bonds broken, and, moreover, what is most improbable, that a double bond is produced from single bonds under circumstances where we should expect the reverse to take place; for it is a well-established principle — one, indeed, on which the knowledge of the constitution of many chemical substances depends — that on oxidation, the molecule is broken at the double bond.

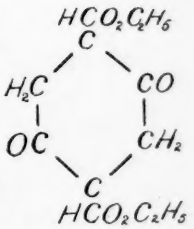
6. *Reduction of Dioxyterephthalic Ether.*—Baeyer‡ has shown that paradioxyterephthalic ether gives on reduction succinylsuccinic ether; and conversely, the latter gives the former on oxidation. The symbol§ of the succinylsuccinic ether has been determined, independently of the dioxyterephthalic ether: it is represented on the following page.

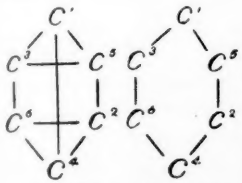
It will be seen that in this the oxygen atoms and the $H\,C\,O_2\,C_2\,H_5$

* Ann. der Chem. 142, 131. †Ann. der Chem., 223, 170.

‡ Ber. d. deut. ch. Ges. 19, 428, 1799. §Ann. der Chem. 211, 306; 219, 71; 229, 45.

groups are para to each other. This is evidently, also, the case with the O H and C O_2 C_2 H_5 groups in the *para* dioxyterephthalic ether. Therefore, it follows that the atoms which are para in a benzol derivative remain also para on reduction to a hexahydrobenzol derivative. This cannot be explained by the prism formula; for this requires that two of the atom-pairs para to each other in benzol become ortho on reduction to hexahydrobenzol (*i. e.* 2, 5 and 3, 6 in the figures below).





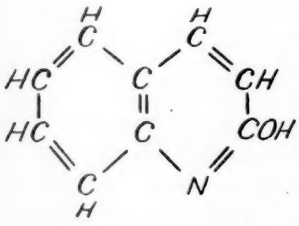
There is, of course, in this case, as in other reactions, the possibilty of a molecular rearrangement; and Ladenburg* thinks this cannot be considered improbable, in view of the extraordinary fact that a C O group is produced from a C O H group by reduction.

7. *Formation of addition products.* — It is well known that benzol and some of its derivatives can be made to form addition products with the halogens. Now, if it were possible to determine the position which these added atoms occupy with relation to each other, it would thus be determined between what atoms the breakable bonds in benzol lie; and this with a considerable degree of certainty, for there is no example of a molecular rearrangement taking place in the formation of halogen addition products.

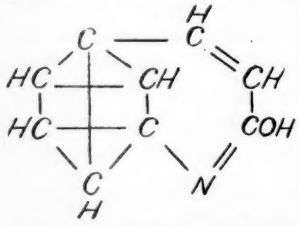
The experiments of Baeyer,† published during the past year, determine the position of one of the breakable bonds. Baeyer finds that tetrahydroterephthalic acid, C_6 H_8 (C O O H)$_2$, takes up two atoms of bromine with the formation of dibromhexahydroterephthalic acid, C_6 H_8 Br_2 (C O O H)$_2$. In order to determine the position of these bromine atoms, they were replaced by hydroxyl by the action of freshly precipitated silver oxide, and the dioxyhexahydroterephthalic acid thus formed gave, on treatment with bromine, tetrabrompyrocatechin. As the latter contains the two hydroxyl groups in the ortho position, this fact offers an argument for the presence of at least one double bond in benzol. Yet it must be admitted that the formation of the tetrabrompyrocatechin in the manner described, is somewhat extraordinary, and that, therefore, an intramolecular change is not very improbable.

8. *Conversion of Carbostyril to Chinoline.* — Carbostyril, which is known to be an ortho derivative, on account of its formation from ortho-

* Ber. d. deut. ch. Ges. 20, 62. † Ber. d. deut. ch. Ges. 19, 1803.



amidocinnamic acid, gives, when treated with phosphoruspentachloride, chlorchinoline*, and from this is obtained, on reduction, chinoline itself. Roser† has called attention to the fact that this furnishes an important argument against the prism symbol; for, since in chinoline the pyridine group, consisting of one nitrogen and five carbon atoms, is known to be present, it is also undoubtedly present in carbostyril. This is clearly indicated in its representation by the hexagon or diagonal symbol.



If, however, the attempt is made to represent it by the prism symbol, in which the ortho atoms are not adjacent, it is found that it does not contain the pyridine group, but another group consisting of one nitrogen and *six* carbon atoms. (See diagrams.)

9. *Comparison of Ortho, Meta and Para Compounds.* — A large number of facts are known which indicate a closer relation between the ortho and para positions than between the ortho and meta, or meta and para. For example: the three nitraniline chlorhydrates are decomposed by water under the same conditions in the following proportions: ortho, 63.8 per cent; para, 13.1 per cent; meta, 3.4 per cent. The ortho and para xylols oxidize much more readily than the meta xylol; ortho and para nitrobrombenzol give with ammonia the corresponding nitranilines, while the meta nitrobrombenzol, like brombenzol itself, is unattacked; meta nitraniline, like aniline, takes up three halogen atoms, while the ortho and para take up only two; and there are a number of other facts of a similar nature. Lellmann,‡ from the fact that an atom substituted in the meta position exercises a less influence on the original compound than if substituted in the other positions, concludes that the meta position is the most distant one in benzol, and therefore prefers the diagonal symbol. This conclusion, of course, rests entirely on the hypothesis that the more distant the substituting atoms from each other, the less will be the effect of the substitution on the original compound. While this has been shown to hold true with one class of compounds (the oxyacids of the fat series), it seems to me we are not justified in supposing it universally true on that account.

* Friedlaender and Ostermaier. Ber. d. deut. ch. Ges. 15, 333.

† Ber. d. deut. ch. Ges. 15, 2348. ‡ Ber. d. deut. ch. Ges. 17, 2719.

FACTS OF A PHYSICAL NATURE.

1. *Heat of Combustion of Benzol.*— Thomsen,* by a comparison of the combustion heats of benzol, dipropargyl and acetylene, comes to the conclusion that nine single bonds must be present in benzol. It would lead too far to enter here into a discussion of the correctness of Thomsen's conclusions in regard to the effect of the constitution of organic bodies on their heats of combustion. Brühl†, however, in a recent criticism on this subject, attacks Thomsen's theories most violently, showing that even his deduction of the fundamental thermal constants rests on assumptions unwarranted by the facts. It does not appear proper, therefore, to attach any weight to the thermochemical conclusions in regard to the constitution of benzol, resting as they do on hypotheses no better established than the structure of that substance itself.

2. *Molecular Volume of Aromatic Compounds.* — Schiff‡ has shown that one double bond causes a difference of four units in the molecular volume of organic compounds. If, therefore, it is found, after making due allowance for the difference in the number of hydrogen atoms, that the molecular volume of aromatic compounds is greater by twelve units than that of saturated fat compounds with the same number of carbon atoms, this would lead to the idea of three double bonds in benzol. As a matter of fact, however, it is found that the molecular volume of aromatic compounds corresponds exactly to that of saturated fat compounds, and is proportionally *less* than that of unsaturated ones. This is, therefore, an indication of nine single bonds in benzol.

3. *Refraction Equivalent of Aromatic Compounds.* — On the other hand, Brühl§ finds that the refraction equivalent of aromatic compounds is in accordance with that calculated for them only on the assumption of three double bonds. The calculation is based on the values deduced from the study of a large number of organic bodies.

Having presented this statement of the important facts bearing on the subject, I shall now pass to considerations of a more general nature, discussing the different symbols separately.

The Prism Symbol.— This symbol possesses one considerable advantage over all other benzol symbols, in that it gives a clear and undisputed representation of the isomeric substitution products, requiring one mono- and three di-substituted benzols. With all the other sym-

* Ber. d. deut. ch. Ges. 15, 331.
† Jour. f. prak. Ch. 35, 181.
‡ Ann. der Chem. 220, 303.
§ Ann. der Chem. 200, 228.

bols, it is necessary to adopt some new idea of what in reality constitutes difference in position. Ladenburg, therefore, although acknowledging that his symbol is not in accordance with the other chemical facts, thinks this fact alone of sufficient importance to warrant adherence to it. But we have seen that there is not a single reaction of aromatic compounds among those able to throw any light on the matter, which is in accordance with the prism symbol. Is it not, then, very much more probable that our ideas of isomerism in case of compounds with closed chains, based as they are on the knowledge of the isomerism of those with open chains, are erroneous, than to suppose that a molecular rearrangement takes place in all the reactions discussed?

But this is by no means the only disadvantage of the prism symbol. Naphthalene is known to consist of two benzol nuclei, having two atoms, ortho to each other, in common. This cannot be satisfactorily represented by Ladenburg's symbol. It is true, attempts have been made to do this, but the symbols proposed are very complicated; for example, that suggested by Meyer* requires that the two nuclei not only be joined to each other by the atoms in common, but also that the opposite atoms be bonded with each other (that is, 2 and 3 of one nucleus to the same atoms of the other).

Neither is the formation of addition products satisfactorily represented by the prism symbol; for there is no more reason why three bonds should be broken than a greater or less number, since all the nine bonds are equivalent. As a matter of fact, however, we know that while three bonds can be broken without any great difficulty, yet it is only the very strongest agents, such as hydroiodic acid, that are able to break a fourth bond. We are, therefore, justified in the conclusion that there are three bonds in benzol of a nature different from that of the other bonds, — a fact not in accordance with the prism symbol.

It seems to me, then, in view of the number and variety of the facts against this symbol, we are fully warranted in an unhesitating rejection of it.

The Diagonal Symbol.—Although not open to all the objections to Ladenburg's symbol, since the ortho atoms are adjacent, yet the diagonal symbol gives, of course, no explanation of the five reactions indicating the presence of a double bond. Moreover, it does not possess the single advantage of the prism symbol in giving a clear representation of the isomeric substitution products; for it is evident that atoms 2, 6, and 4, all stand in precisely the same chemical relation to 1, each being

* Ber. d. deut. ch. Ges. 15, 1823.

directly united with it by one bond, and with atoms 3 and 5 by the other two bonds. This symbol requires, then, only two isomeric disubstituted products. In order to account for a difference between 1, 4 and 1, 2 or 1, 6, it is necessary to make the assumption, either that one of the four bonds of the carbon atoms is different from the other three, or that a difference of position in space is sufficient to give rise to isomerism. The first assumption is contradicted by all the facts with which we are acquainted. A representation in space has, it is true, been suggested in order to account for some other cases of isomerism; for example, that of maleic and fumaric acids, and that of the different tartaric acids. But it is doubtful whether this explanation is correct even in these cases, and it is unnecessary to assume it in benzol, where the chemical facts do not require it.

Besides the relative reactiveness of the ortho, meta, and para compounds, from which it is doubtful whether any conclusion in regard to the bonding can be drawn, the only arguments raised for the Claus symbol are the combustion heat and molecular volume of benzol. These appear to me, however, to furnish an argument against that symbol, rather than in favor of it; for it is certainly very improbable that the three bonds which are so different from the remaining six, either in their character or position, as to cause very marked chemical differences, should exercise no different influence on the physical properties. There seems, then, to be no reason whatever for the adoption of the diagonal symbol.

The Hexagon Symbol.— The advantages of this symbol over those previously discussed are numerous. It offers an explanation of the formation of benzol from ethylene, mesitylene from acetone, and trichloracetacrylic acid from chinon, none of which reactions can be explained by the other symbols. It is, also, in accordance with the fact noticed by Baeyer that the added atoms take the ortho position, and it has the advantage of representing the formation of addition products by the breaking of double bonds, as in the fat series, while in the other symbols it is necessary to suppose single bonds broken. It is also particularly fitted for the representation of naphthalene and other condensation products.

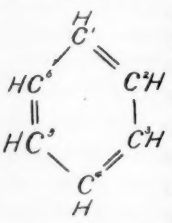
It requires, however, apparently four di-substituted derivatives, the positions 1, 2 and 1, 6, being different. Yet it is to be remembered that this idea is purely hypothetical; for there are no facts known which make it necessary to believe that isomerism is in any way dependent on the nature of the bond. A number of years ago, Kekulé*

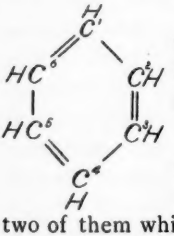
*Ann. der Chem. 162, 86.

brought forward an hypothesis on the nature of valence, which is of some value, as it shows that too much stress should not be laid on the supposed difference between the positions 1, 2 and 1, 6. His hypothesis is briefly as follows: —

"Valence is the relative number of impacts which an atom experiences in the unit of time from other atoms. While the univalent atoms of a biatomic molecule strike one another once, bivalent atoms of a likewise biatomic molecule, at the same temperature, strike each other twice. Under the same conditions, the number of impacts in a molecule consisting of two univalent atoms and one bivalent atom is two for the latter and one for each of the former.

"The benzol formula proposed by me, then, appears as the expression of the following idea: Each carbon atom in the unit of time strikes three times on two other carbon atoms, once on the one, twice on the other. In the same time it comes in contact with the hydrogen atom once. If, now, benzol is represented by the hexagon formula, and any one of the carbon atoms is considered (for example 1), the impacts which it experiences in the first unit of time may be expressed by 2, 6, h, 2, where h signifies that of the hydrogen atom. In the second unit of time, the impacts of the same atom are, 6, 2, h, 6. While the impacts of the first unit of time are represented by the above-given symbol, those of the second are represented by the following: —





"If the above-mentioned conception, or one similar to it, is correct, it follows that the difference between the positions 1, 2 and 1, 6 is an apparent, not an actual one."

In conclusion, some mention ought, perhaps, to be made of the Dewar symbol. Although, as was seen in the study of the chemical facts, there are one or two of them which are better explained by this than Kekulé's symbol, yet there are others with which the reverse is the case. The isomers required by the Dewar symbol are, however, much more complicated, two mono-substituted derivatives being required.

Book Notices.

STEEL FOR HEAVY GUNS.

A DISCUSSION IN THE U. S. NAVAL INSTITUTE.

THE first number of Vol. XIII. of the Proceedings of the United States Naval Institute contains the discussion of Mr. Edward Bates Dorsey's paper on "Steel for Heavy Guns," held at the meeting of the Institute on January 5, 1887.

This paper was distributed widely before the meeting to civil and mechanical engineers, to manufacturers and workers of steel, and to members of the Ordnance Department, to invite comment and criticism. The "discussion," as held at the meeting of the Institute, consisted, in consequence, in the reading of a number of carefully written papers, and also of a number of carelessly written letters, and was not a discussion in the sense of a free interchange of opinions among the speakers.

The position taken by Mr. Dorsey may be summed up as follows: Since the harder varieties of steel have been proved to be inapplicable for structural purposes and for steam-boilers, *a fortiori* they must be inapplicable for guns. In this position he was supported by many engineers and manufacturers of steel, and opposed by the ordnance officers and the steel-makers directly interested in the construction of guns. The papers contributed by those in opposition are the most interesting in the volume, since they give the present practice in the construction of built-up guns, and the principles on which this practice is based. They show that high ductility, with its accompanying low tensile strength, are not the properties required in a gun. It is not only necessary that a gun should not burst; it should not bulge. A gun which is permanently enlarged or distorted is as useless as a gun which is fractured.

The properties needed in gun-metal are a high elastic limit, and a high degree of expansion within this limit. These properties are best developed in the hard steels. Very soft steel, or, more correctly said, ingot iron, is too soft and ductile and has too low an elastic limit to withstand the shock of the explosion without permanent distortion, and the very hard steels are too brittle to stand shock without rupture.

Modern practice in ordnance has adopted a steel of from 0.4 to 0.6 per cent. carbon, with an ultimate strength of 75,000 to 100,000 pounds to the square inch. Guns made in this country of steel of this character have stood very severe tests, with pressures fifty per cent higher than they would have to endure in service, without failure and without revealing any signs of weakness. It would seem to be a difficult matter to obtain the actual facts with regard to the reported failures of Krupp guns and those of other European manufacturers. Contradictory statements are made by the participants in this discussion; some say failures are very frequent, and others that they are very rare. But it must be borne in mind, in any case, that a gun may "fail" without the failure being due to the hardness of the steel or its improper treatment. The proper treatment of steel, particularly hard steel in large masses, is a subject about which there is a great difference of opinion. One might conclude from the frequent use of the words "treacherous" and "capricious" which engineers apply to the harder varieties of steel, that there was something vicious in its nature that made it unworthy of study. And yet it is a well-known fact that moderately hard steel is more reliable in some situations, in which it is exposed to constant vibratory shock, than very soft steel. Steam-hammer piston-rods are made of steel of from 0.5 to 0.8 per cent carbon; the tires of locomotive wheels have a tensile strength of from 100,000 to 140,000 pounds to the square inch; and spring steel of 125,000 pounds to the square inch is a regular article of manufacture. The use of the harder steels for objects which have to withstand shock, is therefore not a new idea, and it seems not unreasonable to suppose that we can successfully treat the large masses of steel needed for guns so as to make them uniform throughout. It is, without doubt, the strains which exist in the mass of metal itself which make the metal fail from apparently insufficient cause — strains produced by the processes of manufacture, such as hammering, rolling, rapid change of temperature, etc.

It is claimed by the ordnance officers, as well as by the makers of gun steel in this country, that the treatment known as oil-tempering will give the desired uniformity and reliability. Oil quenching differs from water quenching in that the cooling effect is less sudden and rapid, and the steel is not made so intensely hard as if it would be if water were used. The subsequent tempering, or partial annealing, modifies the effect of the oil treatment; the internal strains are relieved, and the mass of steel attains a condition of equilibrium. The effect of the treatment decreases, as we might expect, as the thickness of the metal increases. According to Mr. Davenport, of the Midvale Steel

Works, where much of the steel for guns has been made, practical uniformity of molecular condition may be attained in cylinders whose walls are four inches thick.

The principal change in physical properties produced by the oil-temper, is one which has a direct bearing on the use of the metal for guns; namely, a relative increase of the elastic limit and elastic extension as compared with the ultimate strength. For instance, if after cooling in oil, and thereby raising both the ultimate strength and elastic limit, we anneal the mass until the ultimate strength is reduced to nearly its original amount, it will be found that the elastic limit remains much higher than it was originally. This is seen from the following table, in which it will be noticed that the elastic limit in the untreated steel is about forty-one per cent of the ultimate strength, and in the treated steel it is about fifty-two per cent.

TEST OF A PLAIN CYLINDRICAL-HOOP FORGING FOR A TWELVE-INCH RIFLE, BEFORE AND AFTER OIL-TEMPERING.

	Number of specimen.	Position of specimen.	Elastic limit.	Elastic extension.	Ultimate strength.	Elongation after rupture.	Reduction in area.	Specific gravity.
			Pounds.	Thousandths.	Pounds.	Per cent.	Per cent.	
Before treatment	1	inside	34,000	1.333	83,660	18.33	39.20	7.8575
	2	outside	37,000	1.367	88,000	20.50	33.50	
After treatment	3	inside	55,000	2.100	101,660	12.50	33.50	
	4	outside	55,000	1.833	107,160	12.83	30.60	7.8632
	5	middle	53,000	1.833	102,400	13.67	33.50	

The close agreement in the values obtained from pieces taken from the outside, middle, and inside of the forging is considered a proof that the effect of the oil-tempering is uniform throughout the mass. This may be so; but the possibility that internal strains existing in the mass of the metal may be in part relieved in the small portion cut from the interior of the mass, must not be overlooked.

Very little is said in the course of the discussion about the chemical composition of the metal, or about the condition of the carbon in the tempered or annealed metal. It may doubtless be taken for granted that very pure stock is used for this gun-metal, and, since it is made in

the open-hearth furnace, that its hardness is due to the combined effect of carbon and manganese. It would be interesting to know just how much influence the manganese has on the process of oil-tempering, and whether the process is in any degree dependent on the chemical composition of the steel.

The subject of the direct casting of steel guns is only indirectly alluded to in the discussion, although it is evident that many of the participants had the subject in mind. The Naval Institute would do well to arrange a symposium on this subject, also. The advocates of the system of casting steel guns are numerous, intelligent, and earnest, and the Ordnance Department might not have as easy a task in overthrowing their position as they have had in routing the advocates of soft-ingot iron for guns. T. M. D.